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Research Article

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Possible Implications of the Anthropocene on Climate Change and Soil Health

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ABSTRACT

Anthropogenic and climatic factors influence soil's physical, chemical, and biological properties, setting the stage for agriculture's sustainability. Soil is a primary carbon sink crucial for reducing greenhouse gas emissions, making soil health essential for mitigating climate change. Healthy soil enhances climate resilience by maintaining or increasing carbon content and lowering emissions. The overuse of fertilisers pollutes the environment and inadequate application damages soil fertility and microbial activity. The conversion of forests and pastures to agricultural land has resulted in significant carbon losses from the soil. Additionally, soil sealing, air pollution, and industrial contamination all contribute to climate change. Harmful practices such as heavy tillage, land neglect, monoculture cultivation, and excessive chemical use, driven by the pressure to meet growing food demand, have led to soil compaction, degradation, pollution, and nutrient imbalances. Current mismanaged crop and soil techniques deteriorate soil quality; however, by increasing carbon storage in mineral soils and removing emissions from organic soils, sustainable management can contribute to climate neutrality. Climate change can be exacerbated by the release of carbon dioxide into the atmosphere from unsustainable farming practices and poorly managed soils. The purpose of this study is to investigate the detrimental impacts of anthropogenic (Anthropocene) effects on the environment and soil health from a comprehensive perspective and to formulate potential recommendations. The European Union's Green Deal, Bioeconomy, and Farm to Fork initiatives aim to sustainably transform agriculture in response to climate challenges. These strategies aim to reduce chemical pesticide use by 50%, fertilizer use by 20%, and nutrient losses by 50% by 2030 to preserve soil fertility. These management practices include efficient fertilizer use to maintain soil health and mitigate climate change effects. Restoring degraded soils and implementing conservation measures can reduce greenhouse gas emissions and increase carbon storage capacity. Sustainable soil and crop management, including crop rotation, minimizing post-harvest ploughing, preserving vegetation cover, boosting organic matter, and using fertilizers sensibly, is urgently needed to minimize greenhouse gas emissions and store atmospheric carbon dioxide in soil.
Keywords: Soil Properties, anthropogenic and climatic factors.

INTRODUCTION

Intergovernmental Panel on Climate Change (Change, 2024) reported, "There is now new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities." Since then, over 25 years, human activities and human-created problems have changed daily life. Many scientists are trying to understand the current situation. The term "Anthropocene," popularized by scientist Paul Crutzen, denotes the current geological epoch characterized by the significant impact of human activities on Earth's systems (Crutzen, 2006). Significant environmental changes during this era highlight the impact of humans on natural processes. The interplay between climate change and soil health degradation has serious implications for global ecosystems, food security, and human health. The current scientific understanding of nature and geological history is continually evolving. While we were initially limited in knowledge, recent research and technological advancements have significantly expanded our understanding of how human activities impact both nature and geology.

The concept of the Anthropocene, introduced by Italian geologist, Antonio Stoppani in 1873, has gained considerable attention in recent years. Stoppani used the term to describe the growing influence of humans on the environment. The Anthropocene refers to the geological epoch during which human activities became the dominant force shaping climate and environmental changes. Despite increased discussions about climate change and the Anthropocene, scholars still lack a deep understanding of how human actions affect geology and climate. Historical data embedded in the Earth's geological layers—formed over 4.5 billion years—provides valuable insights into past climatic and natural

events. A vertical cross-section of these layers can reveal a wealth of information, highlighting the importance of understanding the impact of post-industrial changes on the future.

When did the Anthropocene Begin?

The Anthropocene may begin around 13,000-16,000 years ago with the advent of agriculture. Although agricultural scientists are still uncovering the specifics of how and when agriculture began to affect nature, evidence from Göbekli Tepe in Southeast Anatolia provides insight into the early impact of human activities (Figure 1).

Scientist William Ruddiman postulated that the onset of farming and the emergence of sedentary populations some 8,000 years ago marked the beginning of the Anthropocene. Even though there were not many millions of people living on the planet back then, it was still comparatively unspoiled compared to the modern world. Large civilizations like the Roman Empire, the classical dynasties of China, the great kingdoms of India, the Napata/Meroitic empire in Africa and the Olmecs and Chavín cultures in the Americas began to alter the environment more than 2,000 years ago, according to historical data. Although there were often large natural barriers separating these civilizations, their activities—like mining—had a significant negative influence on the ecosystem.

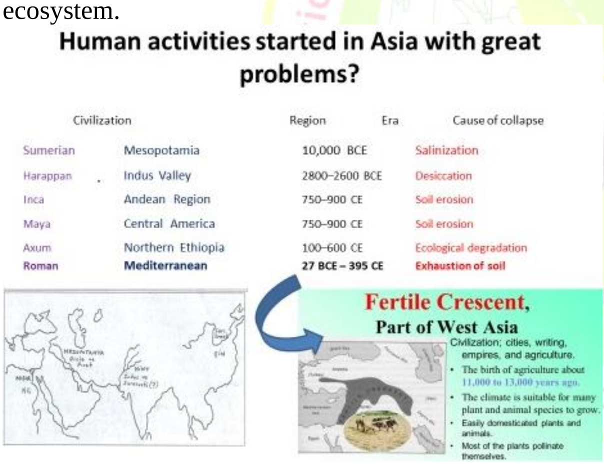

Figure 1. The first human activities began in Asia during the agricultural revolution

According to this perspective, the shift toward agricultural practices marked the beginning of human impact on the environment. The "Agricultural Revolution" led to the destruction of natural areas and forests and contributed to species extinction.

Harvard University professor Dr. David Reich notes that the transition from a hunter-gatherer society to agriculture first occurred in the Harran region of present-day Southeastern Anatolia, which is a part of the Fertile Crescent or Mesopotamia. This region is notable for its wild crops, which are precursors to many of today's staple foods. Alluvial deposits from the Tigris and Euphrates Rivers enrich the soils, making the region suitable for agriculture. As the climate stabilizes, plants and animals adapt to this environment, allowing humans to transition from nomadic to settled agricultural societies. This shift led to genetic changes in crops through artificial selection and breeding, as well as the development of metal tools and weapons, which further altered both the environment and human societies.

The idea behind the term "Anthropocene" is that humankind's significant influence on the planet, which dates back well beyond modern times, characterizes the current age. The term "Anthropocene," popularized by scientist Paul Crutzen, denotes the current geological epoch characterized by the significant impact of human activities on Earth's systems. Nobel laureate Paul Crutzen proposed that the Anthropocene officially began with the Industrial Revolution because of its profound worldwide influence on the environment. By now, a large portion of the Earth's landscape has already undergone major changes because of human activity. According to some researchers, this influence may have begun as recently as 11,700 years ago during the last significant ice age. Originating from the Greek word "anthropoid," which means "human," the phrase "Anthropocene" refers to how human activity has caused widespread extinctions of plant and animal species, contaminated oceans, and changed the atmosphere, among other long-lasting consequences.

Why did the human impact on nature increase after the Industrial Revolution?

When we examine the historical processes of the Earth, the beginning of the industrial era, and the rapidly increasing consumption of fossil fuels, which have witnessed a progressively more destructive course over the last three centuries, we can characterize the Anthropocene epoch. Human intervention in nature leads to much larger changes. Scientists have defined the Anthropocene as a new epoch in which human activities, including those of all living organisms on Earth, have led to an irreversible extinction process. The demand for food security created by a growing population, coupled with an increasing scientific understanding of nature's laws, has led to a transition from an agricultural to an industrial society. After the Industrial Revolution (IR), the world population started to increase, and recently every 50 years, the population has doubled (Figure 2). In the 1930s, the global world population was 2 billion but had grown to 8 billion by 2024. In this period, 6 billion people were added at a four-fold rate.

Extensive petroleum and charcoal usage led to higher CO_2 concentrations in the atmosphere. Experts argue that the Holocene epoch must give way to the Anthropocene starting in the mid-1900s due to factors such as significant land transformations, worldwide species extinctions, increasing sea levels, carbon dioxide emissions, and fast industrialization.

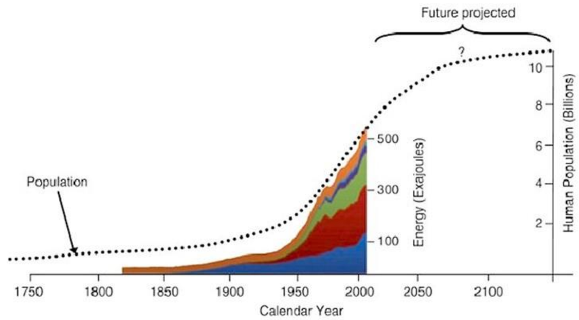

Figure 2. World and continental populations increased from 1961 to 2050 (https://www.change-climate.com/Anthropocene_Anthropogenic_Epoch/Anthropocene_Human_Epoch.htm)

Since the Industrial Revolution, human health care has changed. Human life expectations increased. The size of human agricultural mechanization and advanced technology based on fossil hydrocarbon energy sources' surface ecosystems has changed. The Agricultural Revolution and the Industrial Revolution began 200 years ago, and it further intensified human intervention in nature (Figure 3). Before the Industrial Revolution, the atmospheric CO_2 concentration was 280 ppm; today, 200 years later, they are 420 ppm. However, industrial development has led to the burning of billions of tons of fossil coal and oil, resulting in a 140 ppm increase in CO_2 greenhouse gases in the atmosphere, which is the source of many of the environmental and health problems we face today. The resulting increase in global temperatures from +1.2°C to 1.3 °C has led to significant melting of ice in the Polar Regions, as measured and determined. However, it should be noted that the current unsustainable state, which is defined as climate and ecological crises, is not the result of the civilization and societal order that emerged with the advancement of science and technology but rather the consequence of competitive neoliberal capitalist policies and their advocates, who exploit everything for profit without restraint.

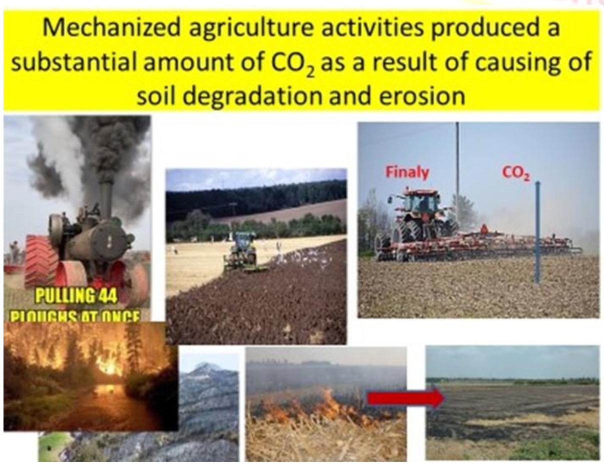

Figure 3. Effects of human activity on greenhouse gas flux to the atmosphere

Human-created differentiation in several areas increased climate change's impact on agriculture and food security. The biggest obstacles to food and water security are population growth, soil-water management, healthy production, and climate change. The two critical issues in the Anthropocene are climate change and soil health degradation. The interplay among these factors has serious implications for global ecosystems, food security, soil, and human health.

The purpose of this study is to investigate the detrimental impacts of anthropogenic (Anthropocene) effects on the environment and soil health from a comprehensive perspective and to formulate potential recommendations.

MATERIALS AND METHODS

A large literature review was conducted on WOS and Scops, and data from many long-term studies were used to determine the Anthropocene effects on soil and crop management. Several soil, plant, water, food, climate change, population growth, and other ecosystem service parameters were collected from the FAOSTAT. (FAOSTAT, 2023) and (Maslin and Lewis, 2015; Our World in Data, 2024) Websites. All data were re-evaluated.

RESULTS AND DISCUSSIONS

Impact of the Anthropocene on Natural Sources

The world has entered an era when the imprint of one species, such as humans, can threaten not only us but also the rest of the biosphere. Unfortunately, human collective activities can drastically affect climate change, biodiversity, and natural resources. Moreover, after the Industrial Revolution, especially in the 21st century, technologies offered huge benefits, were so empowering, and our globe was so interconnected that a small group of people could, by error or by evil intent, create a catastrophe that cascades globally. During the last 200 years, humans have created and/or artificially created several problems. As a result of human activities, several natural processes have been artificially escalated, such as soil erosion, land degradation, deforestation, and conversion of meadow-pasture areas into agricultural land, and water, air, and land pollution have increased. Plant, animal, and organism biodiversity, soil nutrient content, fertility and quality decreased.

Climate Change

Greenhouse Gas Emissions: Increase due to fossil fuel combustion, deforestation, and industrial processes (Figure 4). The source of human-induced climate change began with the Industrial Revolution, which began with Scottish engineer James Watt's patent for a steam engine in 1769 and began with the first fossil fuel-burning machine. As technology has made life easier for years, the average standard of living has increased, leading to more vehicles, machines, and technology, and the uncontrolled burning of fossil fuels has increased. Human activities, particularly since the Industrial Revolution, the use of hydrocarbon fossils for energy greenhouse gas (GHG) emissions have increased. GHG

has amplified the natural greenhouse effect. Naturally, the greenhouse gases released into the atmosphere along with the use of fossil fuels have led to climate change, increasing the temperature of the atmosphere on a global scale.

In recent years, with the development of measurement techniques, more concrete data have been used to calculate the annual and total flows of CO_2 gas. The burning of fossil fuels for energy, deforestation, and industrial processes have raised atmospheric CO_2 levels to unprecedented levels. For instance, before the Industrial Revolution, CO_2 levels in the atmosphere were 280 ppm and reached 419 ppm in 2024, a concentration not seen in millions of years (NOAA, 2024). In a study conducted in the 1960s, it was determined that the global growth rate of atmospheric carbon dioxide increased by about 0.8±0.1 ppm per year, and in the next half century, the annual growth rate tripled, reaching 2.4 ppm per year in the 2010s (Climate, 2024) and now is around 1.8-2.0 ppm (https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide). An increase in atmospheric CO2 concentration also caused global temperature and sea level increases (Table 1)

Table 1. Key Indicators of Climate Change during the Anthropocene

Indicator	Pre-Anthropocene (1700s)	Anthropocene (Current)	Trend
CO2 Concentration (ppm)	280	419	Rising
Global Temperature (°C)	Baseline	+1.1°C	Rising
Sea Level Rise (mm/year)	0.5	3.3	Rising
Ocean pH	8.2	8.1	Falling

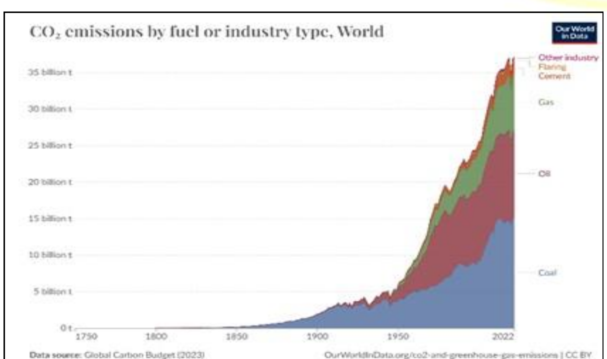

Figure 4. Global release of CO2 (NOAA, 2023)

Global Warming: Accelerated temperature rise leads to extreme weather events. The increasing GHG concentration in the atmosphere also increased the temperature (Figure 5). The consequences of increasing temperature are visible in rising global temperatures, melting polar ice, more frequent extreme weather events, and shifting climate zones.

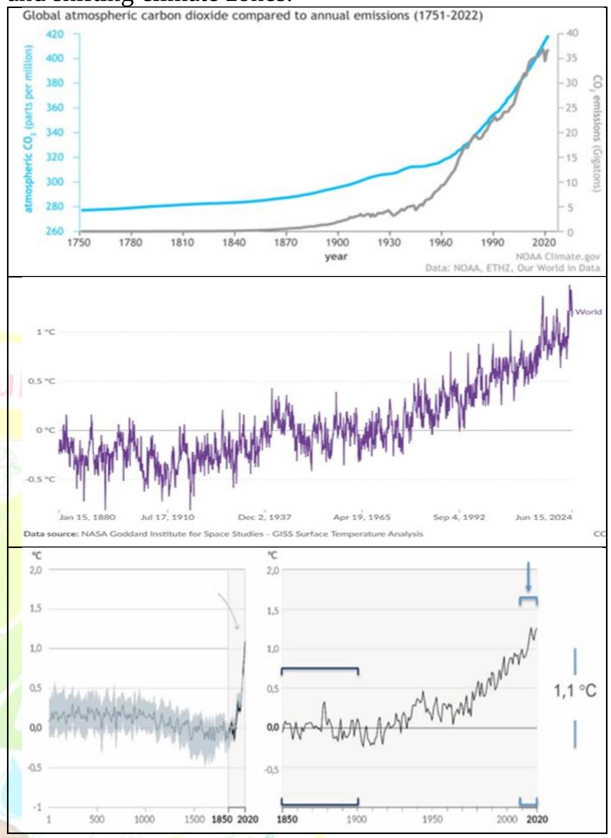

Figure 5. IPCC (2021), “Climate Change Widespread, Rapid, and Intensifying” (https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr)

Per Capita, CO_2 emissions are nearly 20 tons for the USA, 13 tons for China, and the world's mean amount is around 5 tons. It is clear that per capita CO_2 emissions depend on the development population and energy use. Recently, Europe has taken serious measures to reduce CO_2 emissions.

The fundamental principle of an ecosystem, similar to the law of conservation of energy and matter, is that "nothing can be created out of nothing, and what exists cannot be destroyed." However, we can contribute to the preservation and enhancement of nature by learning from it. Moreover, understanding the laws of nature requires living in harmony with it; for example, the practices we propose to combat climate change will also directly contribute to the preservation of nature. (Steffen *et al.*, 2015).

As a result of 200 years of human activities;
Sea-Level Rise: Melting ice caps and thermal expansion contribute to rising sea levels (Table 2).
Precipitation and distribution
Water availability,
Drought conditions,
Runoff,
Potential evapotranspiration,
Changes in soil moisture are affected by global temperature and rainfall.
These factors affect agricultural production and food security. (Ortas, 2022).

Soil Health during the Anthropocene
Relationship between Soil Health and Climate Change
Climate change's global influence on sustainable agriculture depends on efficient management of land use and freshwater resources.
As a result of population expansion and rising settlement demand, agriculturally viable land has been sealed off. Unexpected rural-urban migration has resulted in major issues related to food, water, and settlement. Agricultural land is used for settlements and other purposes due to unintentional land use. In addition, fewer people are employed in agriculture due to the use of technology and rising production costs, which has led to people migrating to urban suburbs. In developed nations, the percentage of the population employed in agriculture is approximately 5%, whereas in underdeveloped nations, it is closer to 50%. This situation triggers the use of agricultural land in urban areas as settlements other than agriculture. This situation negatively affects agricultural production and land assets.
Human actions such as soil and organic matter degradation, erosion, and loss of plant and microorganism biodiversity all have a direct impact on soil health. The Anthropocene over the last year has had significant negative effects. Since humans used heavy tillage with heavy machines on one side, the soil was turned over, and on the other hand, the soil was compacted under the machine wheels. Soil health, the foundation of terrestrial ecosystems, is closely linked to climate change. Healthy soils store carbon, regulate water, and support biodiversity. However, human activities such as industrial agriculture, deforestation, and urbanization have led to soil degradation worldwide.
Soil Degradation: Resulting from intensive agriculture, deforestation, and urban sprawl. In many regions, soil degradation size is enlarged. As a result, soil degradation increases annually in many areas after heavy rains (Figure 6).
Erosion: Loss of topsoil due to unsustainable farming practices and deforestation. As a result of the loss of organic matter, agricultural soil is eroded (Lal, 2015).
Loss of Biodiversity: Reduction in soil organism and plant species diversity, affecting soil degradation and fertility.

Table 2. Soil Health Indicators Affected by Human Activities

Soil Health Indicators	Pre-Anthropocene State	Anthropocene State	Trend
Soil Organic Carbon (%)	3-6	0.5-2	Declining
Erosion Rate (tons/ha/year)	0.1-1.0	10-40	Rising
Soil Fertility (NPK content)	Balanced	Imbalanced	Declining
Soil Biodiversity	High	Decreasing	Declining

Figure 6. Global soil degradation during the Anthropocene (In the near past, human-caused several diseases were happening in Turkey)

Soil Degradation and Organic Matter Decrease
All over the world, >50% of the organic matter in the soil has oxidized over the past 100 years, releasing carbon dioxide into the atmosphere. Strong pressure must be applied to reduce soil degradation, particularly heavy soil tillage, to create a crop management and soil sustainability system (Table 2).
Soil Erosion: Intensive farming practices, deforestation, and overgrazing have accelerated soil erosion. In some regions, soil is lost 10 to 40 times faster than it is replenished.
Nutrient Depletion: The overuse of chemical fertilizers disrupts soil nutrient cycles, leading to reduced soil fertility and crop yields. An example is the decline in soil

organic matter in agricultural lands, which has decreased by up to 60% in some areas.

Desertification: In arid and semi-arid regions, human-induced factors like overgrazing and improper irrigation have intensified desertification. This process affects over 2 billion people worldwide and threatens food and water security.

Ocean Acidification: Increased CO_2 not only contributes to warming but leads to ocean acidification. In the South Pole, increasing temperatures in the poles have caused glaciers to melt (Figure 7). Sea water's pH has been measured in several areas where acidity is increasing and water temperature is increasing. This reduces the ocean's ability to function as a carbon sink, thereby exacerbating climate change.

Figure 7. Increasing temperatures in the poles have caused glaciers to melt.

Deforestation: The conversion of forests to agricultural land contributes to 11% of global greenhouse gas emissions. The loss of forests will reduce the Earth's capacity to absorb CO_2, thus accelerating global warming.

Overgrazing and reducing grasslands

The process of desertification, which occurs when productive land becomes arid due to overgrazing, makes overgrazing a major threat to ecosystems. The following outcomes result from livestock consuming vegetation more quickly than it can regenerate:

Depletion of Vegetation: Overgrazing disturbs habitats and increases soil erosion by removing plant cover (Figure 8).

Lack of Vegetation: The land's capacity to hold water is diminished, and groundwater replenishment is decreased. The lack of plant roots to stabilize soil makes it more vulnerable to wind and water erosion, which reduces the richness of topsoil.

Figure 8. Overgrazing and its devastating impact on desertification (Sources) AnuMeena Care Foundation

Decreased vegetation leads to biodiversity loss and ecosystem disruption, as well as local agriculture. About 40% of the planet's land is at risk due to desertification, which affects over 2 billion people globally. About 70% of drylands are used for extensive livestock grazing, which is a major contributing factor to this problem and is estimated to cause an annual economic loss of $50 billion or more. Rotational grazing to allow pasture recovery, controlled grazing with livestock limits, and restoration initiatives like replanting are some of the solutions.

Agricultural Lands Are Used for Settlements and Other Structures Due to Unintentional Land Use

As a result of population expansion and rising settlement demand, agriculturally viable land has been sealed off. This situation has triggered the use of agricultural lands in urban areas as settlements other than agriculture. This situation negatively affects agricultural production and land assets. Çukurova plane is fertile and rich in plant diversity. In the last 40 years, most of the citrus plantations in the Mediterranean region have been converted into tourism, and plantations have been removed (Figure 9). In the long term, the occupation of agricultural land causes food insecurity (Imran *et al.*, 2023).

Anthropocene-caused Forest and Stubble Burning Influences on Soil Degradation

The number of fires has been increasing at an increasing rate between 1988 and 2023, and in the meantime, large areas are increasing (Table 3). In the meantime, when the average biomass is analyzed from the data, a significant amount of biomass is burned and reflected in the atmosphere as a greenhouse gas. As can be seen in the table, as the number of forest fires in Turkey has increased over the years, soil organisms and other

biodiversity are being lost. In particular, the fires from the Mediterranean to the Aegean region in 2021 are remarkable in terms of both the amount of burned area and biomass. The destruction of a forest ecosystem that cannot be filled with any input from an ecological perspective by such a wide fire is a complete disaster and natural budget collapse.

Table 3. Number of fires and burned areas in Turkey between 1980 and 2023.

Year	Burned Area (ha)	Number of Fires	Estimated Amount of Biomass Burned (tons)
1980	13,000	1,190	1,500,000
1985	16,500	1,870	2,000,000
1988	18 210	1 372	2,145,000
1990	13 742	1 750	2,200,000
1995	7 676	1 770	2,100,000
2000	26 353	2 353	2,000,000
2005	2 821	1 530	2,800,000
2010	3 317	1 861	1,900,000
2015	3 219	2 150	3,000,000
2020	20 971	3 399	2,600,000
2021	139 503	2 793	17,000,000
2022	12 799	2 160	1,800,000
2023	15 520	2 579	2,800,000

Interconnection between Climate Change and Soil Health

Climate change and soil health are interdependent. Degraded soil releases stored carbon, contributing to global warming, and climate change exacerbates soil degradation through extreme weather events.

Increasing population growth creates a serious demand for land-based food production. In addition to combating climate change, agricultural practices are essential for feeding the world's population. Soil is the foundation of all life on Earth. According to the FAO, the terrestrial environment (manly soil) provides more than 99.7% of human food (calories, protein). Not only humans but also other living animals and microorganisms' food is mainly supplied by photosynthesis. An integral component of a solution is the condition of our soil or its lack thereof. In addition to supporting more plant and animal life above and below ground and storing a large amount of carbon taken from the atmosphere through photosynthesis, healthy soils also enable the production of healthier, more nutrient-dense food. Plants require healthy soil for photosynthesis.

In addition to being essential for the production of safe food, soil is also necessary for the well-being of humans and healthy ecosystems. (Ortaş, 2023). The global population has quadrupled over the past century, which has necessitated a major shift in agricultural and soil management practices to produce more food. This has been the primary driver of anthropogenic intervention.

Figure 9. Cost of Mediterranean part of Turkey-Mersin (Anonymous, 2024).

Poor management of farming practices significantly contributes to soil degradation. Degraded soils are more susceptible to wind and water erosion, loss of nutrient-rich topsoil, increased pollution, and sedimentation in waterways. They also lack vital organic matter (OM) and soil microorganisms (Table 4).

When soil health deteriorates, the structure of the climate also deteriorates. The integrity of climate and soil structures affects each other positively and negatively. Factors that damage soil occur as a result of climate change.

In 1965, approximately 46.3 million metric tons of fertilizers were used. The amount rose to 195.38 million tons by 2021 (Figure 10). During that same year, phosphate and potash fertilizers held shares of 24% and 20%, respectively, while nitrogen fertilizers accounted for about 56% of the world's overall use (Steffen *et al.*, 2015). The majority of fertilizer is used in East and South Asia. It has been reported that roughly 23 million metric tons of nitrogenous fertilizers, 12 million tons of phosphate fertilizers, and more than nine million tons of potash are consumed in China alone (Steffen *et al.*, 2015).

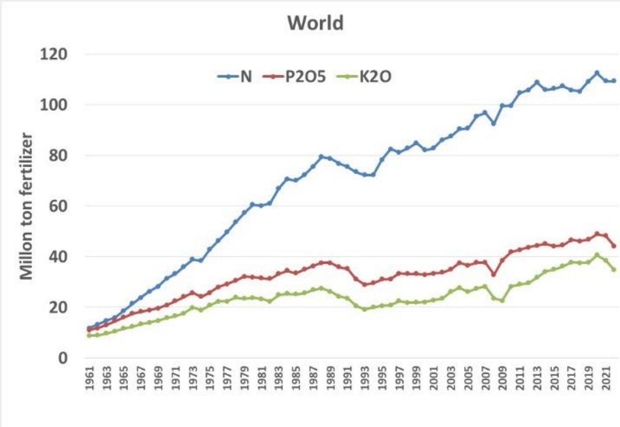

Figure 10. The world's total nitrogen, P_2O_5 and K_2O total fertilizer use (IFASTAT, 2024)

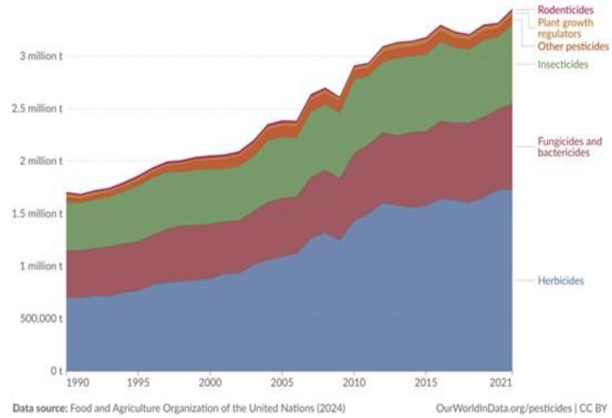

Figure 11. World Pesticide and Herbicide Use over the Last 30 Years

Table 4. Human activities affected agricultural properties before and after Green Revaluation (1960 to 2021)

Indicator	Before Green Revaluation	After Green Revaluation	Trend
Irrigation			Limited
Fertilizer use NPK (kg/ha/year)	20 (46,3)	120 (195,4)	Rising
Insecticide and Pesticide (content)	>1	3	Declining
Agriculture Mechanization			Increased
Wheat production (kg ha per year)	75	325	Rising
Humans (%) can cause wildfires.	0.005	0,035	Increases
Depletion of mineral nutrients			Declining
Water quality-purification			Declining
Changes in soil water			Declining
Changes in plant species			Declining

Pesticide Use is Increasing

All over the world, pesticide breakdown by type is increasing (Figure 11). From 1990 to 2021, the increase was rapid (Our World in Data, 2024). The biodiversity of plants and animals has decreased due to the growing use of agricultural pesticides, which has weakened the biological quality of the soil. Plant growth and human health are among the many adverse effects of the decline in biological productivity and diversity. It is well known that the use of DDT led to the extinction of numerous species living in soil habitats.

What exactly did the Anthropocene marker mean?

Soil and geological horizons, which have characteristics that can endure for years or millennia and retain information about the history of climate and geochemistry, are good candidates. It is now accepted that human activity is the sixth factor in soil creation. It directly affects soil development through processes such as levelling land, trenching, creating embankments, enriching or depleting soil with organic matter, and compaction. Moreover, it indirectly affects soil development through the drift of pollutants or eroded materials.

The World Reference Base for Soil Resources classifies anthropogenic soils as either anthrosols or technosols. Anthropogenic soils include those that have been significantly modified by ploughing, fertilization, pollution, sealing, or enrichment with artefacts. These soils are robust archives of data attesting to the pervasive influence of human activity, so they are trustworthy indicators of the Anthropocene. Certain anthropogenic soils are even referred to by geologists as the "golden spikes" because of their stratigraphic successions, which demonstrate the global influence of human activity like the emergence of unique fossils that identify previous geological epochs. Where will it end? Remains an unanswered mystery. It appears that an international agreement on anthropogenic limits is necessary to stop continued harm. The natural food production limits and the full phase-out of fossil fuels should be the main topics of discussion in this regard. Accelerating the switch to renewable energy in homes, businesses, and transportation should be the focus of efforts rather than restricting the use of fossil fuels.

Possible future effects of the Anthropocene

At the beginning of the 20th century, the use of agricultural chemicals (fertilizers and chemicals for diseases and pests, pesticides, herbicides, and insecticides) was very low. However, since the 1950s, with the modernization and mechanization of agriculture to increase efficiency, the use of chemical fertilizers and pesticides has rapidly increased. (FAO, 2024). In the 1930s, the global world population was 2 billion but had

grown to 8 billion by 2024. In this period, 6 billion people have been added fourfold increase at this rapid pace. The growing global population has increased the demand for land for housing and other purposes.

Every area of life and human activity is political. Every political phenomenon is political. In addition, its solution is political. In this context, policymakers should build strong infrastructures to shape the world we live in, in history, ecology, and the future, in agriculture, technology, and life. In terms of climate change, policymakers should first eliminate administrative waste. Waste management should be provided; it is necessary to adopt rules that include reducing spending on war machines, increasing spending on public education, and supporting sustainable social policies that overlap with other cultures. It is important to develop sustainable policies for the future and to provide funds to close links in the technology chain to compensate for lost time. In this context, politicians should support projects and approaches that protect peace and nature.

The Role of Policy and Global Action

Human activities, especially after the Industrial Revolution, have developed differently, and countries that have produced technology over time based on scientific knowledge have developed and created income differences. While Western Europe and North America, in particular, have problems with access to food with per capita income and production structures, approximately 1 billion people in Sub-Saharan Africa and South Asia have problems with access to food and clean water (Ortaş, 2024).

Food production and daily consumption of potatoes, rice, maize, wheat, and other plant yields are not equal between nations. An unbalanced yield and production quantity situation. Rich countries can access fertilizers and other agricultural inputs; however, poor countries are not able. This is directly related to nations' development, richness, and production potential.

During the pandemic, when a two-week lockdown was implemented globally, greenhouse gas emissions decreased, the environment became less polluted, and birds and other wildlife returned to urban areas. This short-lived experience showed us what we needed to do! In addition, it was revealed that not every nation receives sufficient food, and there is a huge food security problem.

Human activity in nature continues to reduce the ecological budget. The transformation of pasture and meadow areas into agricultural areas continues. The soil structure continues to deteriorate as a result of heavy soil cultivation. The decrease in soil nutrients continues with monoculture farming, and on the other hand, the nutrient content of the soil continues to deteriorate due to excessive nitrogen and phosphorus fertilization. The loss of tropical forests and woodlands is still significant, and greenhouse gas concentrations continue to rise quickly, endangering the stability of the climate system. The global economy is still striving for growth, but little accountability has been taken for the effects this has had on the Earth's system. There is still no planetary stewardship.

However, innovative practices and policies aimed at reducing climate impacts and restoring soil health are urgently needed. Measures to ensure both human and ecological well-being require a new framework that will sustain these efforts, provide robust universal support, and monitor developments. The EU's Green Deal and its civil green and environmental initiatives are significant and have the potential to create new and viable resilient systems. The emergence of coherent and proactive management bodies is crucial for effectively addressing these emerging and future challenges.

International agreements such as the Kyoto Protocol, Paris Agreement, UN Sustainable Development Goals (SDGs) and other peaceful suggestions. There is an urgent need to promote sustainable land use and protect natural ecosystems to stabilize the world. In the 2000s, with the global transition toward sustainable agricultural approaches, there have been efforts to limit chemical use in some regions. The less developed African and Asian nations are not able to use sufficient fertilizers. In Turkey: A similar increase was observed. Since the 1950s, the use of chemical pesticides has become widespread to increase agricultural production, and a significant increase in this use has been noted since the 1980s. Approximately 4 million hectares of agricultural land in Turkey have been diverted from their intended use. With the rapid degradation of approximately 10.25 million hectares, Turkey has found itself on the global desertification map. This phenomenon, which affects 13.88% of Turkish soil, underscores the increasing importance of food security.

Mitigation and Adaptation Strategies

To reduce the effects of climate change on soil health, fertility, and productivity, several integrated approaches and challenge strategies are needed. Possible novel strategies:

Carbon Farming: To increase soil organic matter, carbon budget C sequestration, and carbon mitigation are important. To enhance carbon sinks and reduce soil erosion, land surface restoration is necessary. Practices like agroforestry, cover cropping, and reduced tillage can enhance soil carbon storage.

Sustainable Agriculture: Practices like crop rotation, cover cropping, and reduced tillage to maintain soil health. Adopting organic farming, precision agriculture, and permaculture can reduce the environmental impact of farming and improve soil health.

Soil Reforestation and Afforestation: Initiatives to reclaim degraded lands and restore soil health by restoring forests, regenerative agriculture, and ecological farming practices can help carbon sequestration to improve soil health and combat desertification.

Climate-Resilient Crops: Developing and planting crops that are resilient to changing climate conditions and adaptable to changing climate can ensure food security while protecting soil health.

CONCLUSION

The future impacts of the Anthropocene on climate change and, consequently, soil quality, health, and food security are profound and multifaceted. As environmental effects shaped by human activities increasingly deteriorate, the ultimate challenge for humanity will be to balance development with sustainability. Climate change is likely to worsen soil degradation, reduce agricultural productivity, and further disrupt ecosystem balance.

The Anthropocene was a defining period in Earth's history marked by significant human-induced changes in climate and soil health. The challenges posed by these changes are immense, but by understanding their interconnectedness and implementing sustainable practices, we can mitigate their impacts. Protecting soil health is crucial not only for food security but also for combating climate change. As we move forward in the Anthropocene, a balanced approach that respects both our natural environment and the needs of humanity will be key to a sustainable future.

In conclusion, human activities initiated to understand natural processes and the integrity of ecosystems have caused much more damage to nature than expected. In the last few centuries, the Industrial Revolution and the Information Age have intensified human intervention in nature, leading to the current state of crisis. As stated, "the end of nature is near." If the current situation is not the result of a natural cycle, then we are now in an irreversible process with little time left. We must find new mechanisms and methods that are compatible with nature's carbon cycle. The solution lies in transitioning from fossil fuels to renewable energy sources, drastically reducing activities that harm nature and the climate, especially those that emit carbon dioxide into the atmosphere.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

OPEN ACCESS

Suitability of *Melia dubia* Based Agroforestry in Eastern Uttar Pradesh, India

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ABSTRACT
Agroforestry is being promoted commercially due to the growing need for wood and wood products. However, the progress made in structured agroforestry promotion is limited due to the lack of suitable fast-growing species with improved productivity. *Melia dubia* has been identified as a promising fast-growing tree species that can be incorporated into different agroforestry systems under appropriate circumstances. Given the wide demand for this species, a demonstration plot of *Melia dubia* with intercrops (paddy, wheat and maize) was established at a spacing of 5 m × 5 m, 4 m × 5 m and 4 m × 4 m in the Karchana block of Prayagraj district in Uttar Pradesh in the year 2023. The annual assessment of early growth performance of *Melia dubia* trees after one year depicted that *height increment was in* the *range of 6.54–7.02 m and* girth at breast height (GBH) *increment was* in between 13.06–13.86cm respectively for T_1 (tree + agriculture), T_2 (sole trees), T_3 (tree + agriculture), T_4 (sole trees), T_5 (tree + agriculture), T_6 (sole trees), T_7 (sole agriculture). The growth performance of trees was inferior in control plots (without intercrop) as compared to intercropped plots. The agriculture crops yield for the paddy, wheat and maize crops were 37.8-38.3 qt/ha, 32.9-33.5 qt/ha and 18.7-19.6 qt/ha respectively. There was no substantial difference in agricultural crop yield after one year of tree planting. *Melia dubia* tree typically yields four quintals of wood after harvesting for five years. The present market value of a *Melia dubia* tree is Rs. 0.03-0.04 lakh. Thus, on average, from 400 trees at a spacing of 5 m x5 m, Rs. 14.0 lakh may be gained per hectare after 5-6 years. Thus, the agroforestry system based on *Melia dubia* is a good choice of species for farmers of eastern Uttar Pradesh.
Keywords: *Melia dubia*, agroforestry, intercrops, growth performance, economics of tree.

INTRODUCTION
Agroforestry is an effective approach to addressing environmental concerns and meeting the needs of a rapidly growing human population in a sustainable manner. Sustainability depends on fertile soils, which can be effectively preserved and improved through agroforestry practices. Including trees on agricultural lands can help address various agricultural issues such as sustainable biological production, deforestation, declining soil fertility, droughts and excessive use of harmful chemicals (Arya *et al.*, 2018). Trees in agroforestry systems contribute to improved soil organic matter, nitrogen retention, water-holding capacity and soil infiltration rates. They also aid in preserving soil fertility through nitrogen fixation and the return of organic matter through leaf fall (Rosenstock *et al.*, 2014). Agroforestry is a highly sustainable agricultural practice that not only fulfils our basic needs for food, fuel and fodder but also contributes to the creation of healthier ecosystems for all living beings. Agroforestry is a low-input system that involves integrating trees with crops in different combinations or sequences (Upadhyay *et al.*, 2021). Therefore, researchers, policymakers and others in India have been focusing on agroforestry because of its perceived potential to significantly boost economic growth, reduce poverty, improve the environment and preserve biological diversity. Thus, agroforestry is a crucial tool for integrated and sustainable development (Pal *et al.*, 2011).

In addition to helping to improve soil quality, increase farm earnings, reduce deforestation, and act as carbon sinks, agroforestry systems also benefit food security (Nanda *et al.*, 2021). Asia has seen a sharp rise in the amount of agroforestry-related research; India and China, with their supportive institutions and policies, are hotspots for agroforestry studies, which may have contributed to both nations' increased forest cover shares worldwide (Shin *et al.*, 2020). Traditional agroforestry practices promote species diversity and demonstrate biodiversity reserves that require more investigation and management (Saikia *et al.*, 2017). Agroforestry practices have demonstrated great potential in the current climate change scenario as an approach to reducing the negative impacts of the phenomenon.

Among the most significant problems facing farmers nowadays is a yearly income decline per acre compared to a sudden increase in the value of agricultural land. Planting specific tree kinds, like *Melia dubia*, which are highly valued in the market, have a guaranteed repurchase and require minimal maintenance, can be beneficial in this regard. Furthermore, the trees benefit the plant by limiting the increase in temperature and regulating the release of gases into the atmosphere. *Melia dubia* is a fast-growing, native, multipurpose tree species with significant economic value. At a young stage, it develops quickly in the damp deciduous forest and is a moderately light demander (Kumar *et al.,* 2013). In comparison to traditional *Eucalyptus* species, new and alternative industrial wood species like *Melia dubia*, *Dalbergia sisso* and *Leucaena leucocephala* have been identified as superior sources of pulp wood. These species were developed by Tamil Nadu Agricultural University (TNAU) under National Agricultural Innovation Project (NAIP) on industrial agroforestry (Ramasamy, 2014). To investigate the suitability of *Melia dubia* tree in various cropping systems and promote this agroforestry system through farmer's participation, a demonstration plot was established on a farmer's field in Trans-Yamuna region of Prayagraj, Uttar Pradesh.

MATERIALS AND METHODS

Study area description

Prayagraj, which was formerly known as Allahabad, is among India's oldest cities located at the confluence of the Ganga, Yamuna and Saraswati rivers. The city is situated in the southern region of Uttar Pradesh, spanning over an area of 5482 square kilometres, lying between 24°50′ and 25°40′ North latitudes and 81° 30′ to 82°20′ East longitudes, with an elevation of 322 feet (98 meters). The climate of Prayagraj is temperate. On average, Prayagraj receives 928.79 millimetres of rainfall annually. There are twenty-three development blocks and seven tehsils in the district (Fig. 1).

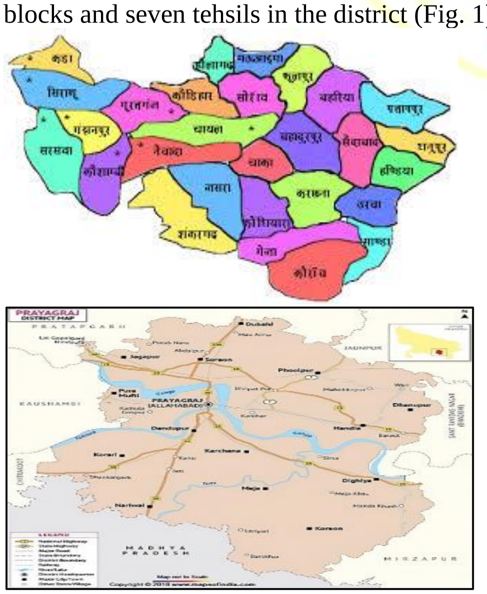

Fig. 1: Maps of Prayagraj district

Establishment of experimental trial

A demonstration plot of *Melia dubia* (Dev variety) was established in the Karchana block of Prayagraj district in the year 2023. The trial consisted of three replications with a spacing of 5 m × 5 m, 4 m × 5 m and 4 m × 4 m respectively (Table. 1 & Fig. 2) and was carried out under a randomized block design (RBD). At the beginning of the monsoon season, a mixture of 100 grams of NPK (3:2:1) fertilizer and 1.0 kilogram of farmyard manure (FYM) was applied to each plant to aid in growth establishment. Irrigation was carried out once a week during hot summer months and twice a month during other times. The growth parameters, including height and gbh were measured annually to calculate the increment.

Table 1. Details of treatments used for the study

Treatment No.	Treatments
T_1	Tree (5 m × 5 m) + Agriculture
T_2	Tree (5 m × 5 m) sole
T_3	Tree (4 m × 5 m) + Agriculture
T_4	Tree (4 m × 5 m) sole
T_5	Tree (4 m × 4 m) + Agriculture
T_6	Tree (4 m × 4 m) sole
T_7	Agriculture sole

Fig. 2. Intercropping of *Melia dubia* with Maize

Data analysis

RBD and the traditional Analysis of Variance (ANOVA) method were used for the statistical analysis of the data. The statistical analysis was carried out using the OPSTAT data analysis tool package, which was developed by the Statistical Software Package for Agricultural Research Workers, CCS HAU, Hisar, Haryana (Sheoran *et al.,* 1998).

RESULTS AND DISCUSSIONS

The research was conducted in the Karchana block of Prayagraj district in 2023-24, focusing on farmers' fields. One-year-old *Melia dubia* plantation was taken into account for the study. Observations on the height and gbh of the *Melia dubia* plants were made at the time of plantation and one year of age. The plant height ranged from 0.26 to 0.35 m at the initial stage and from 6.54 to 7.02 m at one year, indicating rapid growth. The plant gbh ranged from 0.3 to 0.45cm at the initial stage

and at one year, gbh ranged from 13.06 to 13.86 cm, showing increase in stem girth.

After a year of planting, it was found that T_1 (tree + agriculture) had the highest increment in girth (13.86 cm), followed by other varieties, with T_6 (control) having the lowest value (13.06 cm). Based on the statistics on height, treatment T_1 performed better than other treatments, followed by T_3 and T_5, while treatment T_6 has the lowest values. After a year of planting, T_1 performed well based on trends in both height and girth data (Table 2 & Fig. 3).

Table 2. Growth performance of *Melia dubia* after one year

Treatments	Height increment (m)	Girth increment (cm)
T_1	7.02	13.86
T_2	6.56	13.39
T_3	6.79	13.75
T_4	6.69	13.31
T_5	6.71	13.47
T_6	6.54	13.06
CD (5%)	N/A	0.34
SE(m)	0.097	0.107
SE(m)	0.138	0.151
C. V.	2.507	1.371

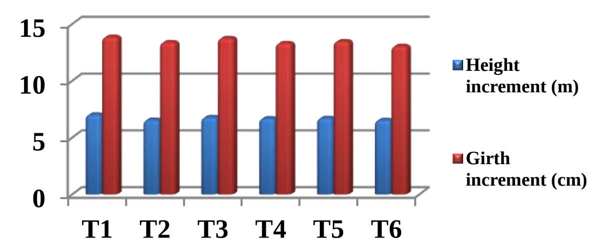

Figure 3. Growth performance (height & girth) of *Melia dubia* after one year

Intercropping yield

The results of the intercropping of paddy in T_1 (*Melia dubia*-based agroforestry) showed highest crop yield of 37.8qt/ha, whereas T_7 (sole agriculture) recorded higher with 38.3 qt/ha (Table 3 and Fig. 4).

Table 3. Paddy yield (qt/ha)

Treatments	Paddy yield (qt/ha)
T_1	37.8
T_3	37.5
T_5	36.7
T_7	38.3

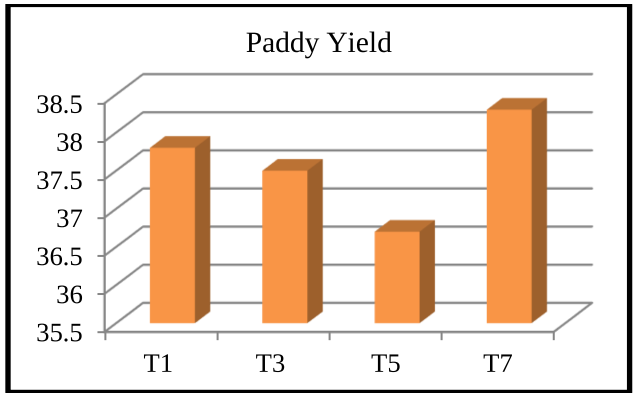

Fig. 4. Paddy yield (qt/ha)

The results of the intercropping of paddy in T_1 (*Melia dubia* based agroforestry) showed the highest crop yield of 32.9 qt/ha, whereas T_7 (sole agriculture) recorded higher with 33.5 qt/ha (Table 4 and Fig. 5).

Table 4. Wheat yield (qt/ha)

Treatments	Wheat yield (qt/ha)
T_1	32.9
T_3	32.6
T_5	31.8
T_7	33.5

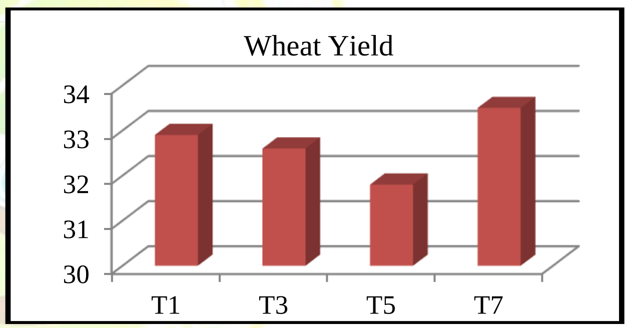

Fig. 5. Wheat yield (qt/ha)

The results of the intercropping of paddy in T_1 (*Melia dubia* based agroforestry) showed highest crop yield of 18.7 qt/ha, whereas T_7 (sole agriculture) recorded higher with 19.6 qt/ha (Table 5 and Fig. 6).

Table 5. Maize yield (qt/ha)

Treatments	Maize yield (qt/ha)
T_1	18.7
T_3	18.4
T_5	18.2
T_7	19.6

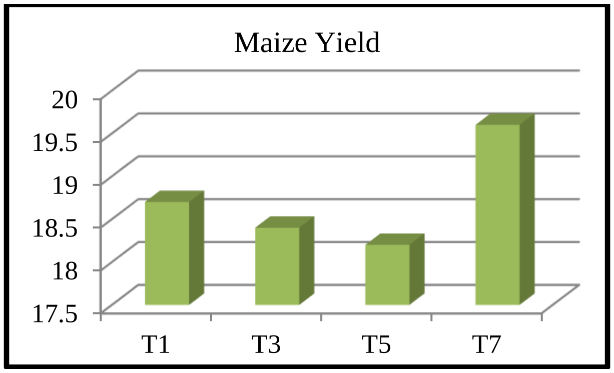

Fig. 6. Maize yield (qt/ha)

The benefits of planting *Melia dubia* in an agroforestry system have been reported by Dhiman and Gandhi (2017) and Goswami *et al.*, (2020). Kulkarni (2017) also reported that *Melia dubia* did not have any negative effects on the growth and yield of crops in the agroforestry system. Narender *et al.*, (2023) found that in intercropped conditions, the tree parameters of *Melia dubia*, such as tree diameter at breast height (DBH), tree height and canopy spread, were higher than those without intercrops. Trees with intercrops exhibited more canopy spread, tree height and DBH (6.9 m, 16.3 m and 56.6 m) compared to pure stands (6.6 m, 16.2 m and 55.6 m) of *Melia dubia* trees. Ajaykumar *et al.*, (2022) studied intercropping with *Melia dubia* in three different spacings: S_1 (3 m × 1.5 m), S_2 (3 m × 3 m) and S_3 (4 m × 4 m), while S_0 represented open field (sole crop) for both seasons. They found that wider spacing of S_3 (4 m × 4 m) could be recommended for intercropping under *Melia dubia* plantations for up to 4 years. In comparison to other medicinal agroforestry systems, Meshram *et al.*, (2024) reported that the *Melia dubia + Clerodendrum phlomidis* agroforestry system had the highest overall gross returns, net returns and benefit-cost ratio. To support farmers, the marketing of end products should be strengthened through collaboration with project planners and wood-based industries (Srivastav *et al.*, 2019).

CONCLUSION

Melia dubia did not adversely affect the growth of trees and yield of crops grown in the agroforestry system. Based on the results of the current study, it can be concluded that sole agriculture performed a little superior than the intercrops, but in view of anticipation of sale of trees and intercrops after harvesting period may definitely give more returns compared to sole crop system to agroforestry system, as from sale of a *Melia dubia* tree, Rs. 0.03-0.04 lakh or from 400 trees per ha at a spacing of 5 m × 5 m, Rs.14.0 lakh may be gained. The successful implementation of *Melia dubia* based agroforestry systems can bring multiple benefits for farmers and the environment. These systems can generate additional income through diverse revenue streams while also improving soil health and productivity. By integrating *Melia dubia* into their practices, farmers can achieve sustainable land management, increase crop yields and contribute to environmental conservation efforts. Future research and development efforts should be prioritized for optimizing cultivation practices, enhancing genetic varieties and exploring new applications of *Melia dubia*. By unlocking its full potential, *Melia dubia* can play an important role in advancing agroforestry as a viable solution for sustainable development and mitigating the impacts of climate change.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

OPEN ACCESS

Assessment of Microbial Quality of Milk Products (Wara and Nunu) Sold in Ilorin

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ABSTRACT
Microbial contamination is a major problem due to unhygienic handling and processing. This study evaluated the microbial safety of milk products sold in Ilorin. The samples were obtained commercially from nine locations in the 3 local government areas of Ilorin respectively with a controlled sample. The samples collected were subjected to physicochemical and microbial parameters using standard methods. Physicochemical analyses of Wara samples showed that the titratable acidity and pH ranged from 0.07-1.19g/l and 5.74-7.19, respectively, while that of the Nunu sample had a value for titratable acidity and pH varying from 0.04-2.35 g/l and 4.23-4.61. Genomic identification of some of the isolates reported the presence of enteric bacteria such as *Serratia surfactantfaciens, Enterobacter soli, Salmonella bongori, Pseudomonas inefficax* and *Klebsiella oxytoca* from the commercial samples capable of causing gastrointestinal illnesses if consumed in sufficient amounts. This study showed that although the physicochemical and proximate properties of the commercial samples were good, the presence of pathogenic bacteria as a result of the poor hygienic handling of the producers of these milk products makes them relatively unsafe for human consumption, especially if large quantities of these bacteria are present in the product and consumed. Proper storage and good hygiene during production are thus important to ensure safety of the products.
Keywords: Hygiene, Safety, Genomic, Handling, Pathogen.

INTRODUCTION

Food safety has been of concern as poisoning caused by food consumption has increased, raising the need for processing and producing foods with high quality and safety (Sobukola *et al.,* 2010). Most small-scale food processing firms pay little or no attention to hygiene during food processing leading to the production of foods with low quality assurance (Adetunji and Chen, 2011). Unpasteurized milk contains microbes that are potential foodborne pathogens; however, the low pH obtained during fermentation of the milk to other products does not eradicate these microbes and could be transferred to the consumers. Viruses, rickettsia, bacteria and fungi may be found in raw milk as the udder of cattle often harbours several microorganisms (Okonkwo, 2011). Contamination of dairy products by microorganisms such as *Escherichia coli, Staphylococcus aureus, Pseudomonas* spp., *Bacillus* spp., *Micrococcus* spp. and *Klebsiella* spp. has been reported due to the poor hygienic conditions in which they are processed and the water source (Ifeanyi *et al.,* 2013; Afolabi *et al.,* 2017). Subsequently, this leads to cases of infections and in some cases intoxication as a result of toxins produced by these organisms (Stewart and Humphrey, 2002). Nunu means cow's milk in the Fulani language and is often hawked by women (Abdulkadir and Mugadi, 2012). It has a milky or opaque white colour and is produced traditionally by carrying out lactic acid fermentation of fresh cow milk (Omola *et al.,* 2019). In Nigeria, local cheese production is widely done and is known as Wara in the Northern region of Benin Republic, Wogachi is used to refer to locally made cheese. Wara production is believed to have originated in the Northern part of Nigeria as most of them are mainly nomadic farmers, however, this has spread to other parts of the country including Ondo, Oyo and Kwara States (Bamidele, 2006). Lack of knowledge and non-compliance to hazard analysis and critical control points associated with the production of milk and its production has led to the contamination of some locally made dairy products. Milk thus requires adequate attention during processing to ensure contaminants are not introduced in the final product. There is a dearth of information on the perception and the safety of these milk and milk products sold in Kwara state, Ilorin. The present study was aimed at filling this gap. This is necessary to ascertain the microbial quality and safety of some of the milk products sold in selected locations in Ilorin. Therefore, this study was aimed at carrying out the safety evaluation of some selected milk products (Wara and Nunu) in Ilorin.

MATERIALS AND METHODS

Study Location

This study was carried out in Ilorin metropolis in Kwara State, Nigeria. It is the capital of the State and is made up of indigenes who are farmers, public servants and students. Its houses some food, and pharmaceutical industries as well as a federal government-owned university with an estimated population of 77,667 (2006 Population Census). Three local governments, namely: Ilorin West, Ilorin South and Ilorin East were selected for this study.

Sample Collection and Preparation (Wara and Nunu)

Fresh cow milk was aseptically collected from cows in Osin farm, Ilorin, Kwara State for the production of Nunu and Wara between 6:30 am-8:00 am (during milking), which cooled and kept under refrigerated condition before processing. Collected samples were transported to the laboratory immediately where production was carried out.

One litre of sterilized fresh cow milk was put in a metallic pot to which 10 ml of starter culture was added. The starter culture is a culture of lactic acid bacteria which is added to the milk to acidify it, inhibit unwanted bacteria as well as enhance the quality of the drying process. The heating was done at 68°C for 20 min for the milk to clot. The resultant mixture was allowed to cool at a renneting temperature (the appropriate temperature for coagulation of milk) of 31°C. The curd (coagulated portion) was separated from the whey (non-coagulated portion) using a sterilized sieve; 150 ml of sterile water with a temperature of 50°C was added to the curd while stirring continuously for 45 min and this washing process was maintained at 34°C to remove the leftover whey in the curd. The washing process also aids in reducing the lactose concentration thus reducing the acidity of the curd. Stirring was stopped and the curd collected in porcelain cloth and left for 15 min to drain out the water. The curd was further pressed into mould to obtain the final Wara product.

A modified method by Owuzu-Kwateng *et al*. (2010) and Akabanda *et al*. (2010) was used for the production of Nunu. Collected cow milk in a sterile container was screened and allowed to ferment for 48 hours at room temperature. Using a wooden ladle, the fermented milk was churned; fat was removed while the excess whey drained off to obtain the product (Nunu) with a thick consistency.

Physicochemical Analyses

Titratable acidity

This was determined using the method by AOAC (2000)

Determination of pH

The pH of all samples was determined at room temperature (29 °C) using a digital pH meter (JENWAY 3505) according to AOAC, 2005 (Nielsen, 2002).

Microbiological Analysis

Sterilization of materials

The glassware including test tubes, conical flasks, measuring cylinder and McCartney bottles used in this study were properly washed with detergents, rinsed with water, wrapped with aluminum foil and sterilized in the hot air oven at a temperature of 170 C for 1 hour. Inoculating needles and loops were flamed to redness on the Bunsen burner. All media were sterilized in the autoclave at 121 C and 15psi for 15 minutes; upon cooling (43±2 C) of the sterile medium, the discrete conical flask's brim was flamed before dispensing the respective medium. Sterile Petri dishes and micropipette tips were used during analyses. The workbench was properly disinfected using 70% ethanol-soaked cotton wool.

Sample collection

The experimental analyses of the discrete samples were undertaken at the Microbiology laboratory of Nigerian Stored Products Research Institute (Headquarters), Ilorin.

Preparation of Culture Media

All media were prepared according to the specifications of the manufacturer(s).

Characterization and identification of isolates

Characterization and subsequent identification of bacterial isolates (Bergey's Manual) were based on colonial and microscopic observations, biochemical tests and molecular studies. The colonial morphology observed includes the shape, colour of colony, elevation, edge, optical characteristics and surface texture of the colonies. The cellular morphology of the bacteria isolates was determined through Gram staining with photomicrography. Catalase, Coagulase, Citrate, Indole, Sugar fermentation, Starch hydrolysis, Oxygen relationship, Methyl red and Vogues Proskauer were undertaken biochemical tests. Molecular studies were done at the International Institute for Tropical Agriculture (IITA), Ibadan.

RESULTS AND DISCUSSIONS

Physicochemical property

The titratable acidity and ph were as presented in Table 1. TTA of wara samples collected within the Ilorin metropolis varied significantly ($p>0.05$) and ranged from 0.07 - 1.19g/l. The highest TTA value was recorded for MDW, while the lowest value was recorded for GKW. These values are in line with the findings of Zalan *et al*. (2005), however a slightly higher than the values reported by Veljovic *et al.* (2007). The variation in TTA values might be attributed to different levels of fermentation that take place during the production and sales of Wara. The case was quite different for pH values obtained for these samples as samples collected from Ilorin East and West recorded pH values of above 7. The lowest pH value was recorded for TKW. This is in line with the reports of Laba *et al*. (2015) who reported different pH values for Wara samples collected at different locations in Ilorin. The variation in pH values of Wara obtained from the Ilorin metropolis might be attributed to non-standardized processing and handling techniques for Wara production in these regions.

Table 1. TTA and pH of *Wara* samples

Sample	TTA (g/l)	pH
MDW	$1.19^{f}\pm0.00$	$7.1^{c}\pm0.01$
ASW	$1.03^{e}\pm0.04$	$6.77^{b}\pm0.02$
IDW	$0.93^{d}\pm0.05$	$7.04^{c}\pm0.00$
GBW	$0.02^{a}\pm0.00$	$7.19^{c}\pm0.00$
PFW	$0.18^{c}\pm0.01$	$7.18^{c}\pm0.00$
SGW	$0.18^{c}\pm0.01$	$5.90^{a}\pm0.00$
TKW	$0.11^{b}\pm0.00$	$5.74^{a}\pm0.02$
OGW	$0.09^{b}\pm0.00$	$5.82^{a}\pm0.00$
GKW	$0.07^{b}\pm0.00$	$5.90^{a}\pm0.00$
CCW	$1.00^{e}\pm0.00$	$6.12^{c}\pm0.00$

Results represent Mean±SD of triplicate determinations. Means with different superscripts are significantly different (p=0.05) along the rows. TTA- Titratable acidity, MDW=Mandate Wara, ASW=Asa-dam Wara, IDW= Idiape Wara, GBW= Gambari Wara, PFW=Post office Wara, SGW=Songo Wara, TKW=Tanke Wara, OGW=Offa Garage Wara, GKW=Gaa Akanbi Wara

The Titratable acidity and pH of Nunu samples are shown in Table 2. The total titratable acidity (TTA) of the Nunu samples ranged from 0.03 to 2.35 g/l whereas that of the control prepared sample was 0.08 g/l. The peak value obtained in this study is quite higher than the peak values reported for Nunu sold in the Kano metropolis by Omola *et al.* (2019). The high acidity explains why Nunu has a sour taste and may be due to the variation in the duration of the fermentation period and method of production. There was no significant difference in the pH of Nunu samples. However, the peak value (4.70) was recorded for control Nunu while that of the Nunu sold in Ilorin ranged from 4.23 to 4.61. pH value obtained corroborates with the findings of Shibdawa *et al.* (2018), who reported a pH range of 4.6 – 4.8 for Nunu sold in the Bauchi metropolis. Beresford *et al.* (2001) reported that the optimum pH for the growth of most common bacteria is around neutral and growth is often poor at pH values < 5.0. This implies that Nunu sold in Ilorin are not prone to microbial growth and cannot therefore cause any form of microbial food poisoning.

Table 2. TTA and pH of *Nunu* sample

Sample	TTA (g/l)	pH
MDN	$0.04^{b}\pm0.00$	$4.44^{a}\pm0.00$
ASN	$0.04^{b}\pm0.00$	$4.44^{a}\pm0.00$
IDN	$0.04^{b}\pm0.00$	$4.44^{a}\pm0.00$
GBN	$1.35^{f}\pm0.00$	$4.35^{a}\pm0.00$
PFN	$2.29^{g}\pm0.00$	$4.25^{a}\pm0.00$
SGN	$2.35^{g}\pm0.00$	$4.23^{a}\pm0.00$
TKN	$1.27^{d}\pm0.00$	$4.32^{a}\pm0.00$
OGN	$0.03^{a}\pm0.00$	$4.31^{a}\pm0.00$
GKN	$1.34^{e}\pm0.00$	$4.61^{a}\pm0.00$
CCN	$0.08^{c}\pm0.00$	$4.70^{a}\pm0.00$

Results represent Mean±SD of triplicate determinations. Means with different superscripts are significantly different (p=0.05) along the rows. TTA- Titratable acidity, MDN=Mandate Nunu, ASN=Asa-dam Nunu, IDN= Idiape Nunu, GBN= Gambari Nunu, PFN=Post office Nunu, SGN=Songo Nunu, TKN=Tanke Nunu, OGN=Offa Garage Nunu, GKN=Gaa Akanbi Nunu

Identification and Characterization of Bacteria Isolates of Wara and Nunu Sold In Ilorin

The genomic characterization of microbial isolates is shown in Table 3 respectively. The percentage identity shows the relatedness of the isolates to the bacterium also found in the NCBI database (National Center for Biotechnology Information). The result shows the presence of *Serratia surfactantfaciens*, *Enterobacter soli*, *Salmonella bongori*, *Pseudomonas inefficax* and *Klebsiella oxytoca* which are all enteric pathogens. The genomic technique makes use of the nucleotide sequence of the isolates and, as such is a more reliable method for the identification of organism. The use of genomics in the identification of microorganisms has been effective in the study of pathogenic organisms as the method is more reliable compared with the use of biochemical tests and serology.

DNA fingerprints bacteria were generated by polymerase chain reaction using a primer based on the repetitive elements found in the genome the isolates. The molecular analyses of isolated bacteria were identified on 1.5% agorose gel electrophoresis that showed Size of the amplicon at 1500 bp (base pair).

Identification of some the isolates using genomic (molecular) technique showed the presence of enteric bacteria including *Klebsiella oxytoca*, *Serratia surfactantfaciens*, *Salmonella bongori*, *Pseudomonas inefficax* and *Enterobacter coli.* These are Gram negative bacteria capable of causing gastrointestinal illnesses such as Salmonellosis, Urinary Tract infection, septiceamia and outbreaks of nosocomial infections (Chavez Hernandez, 2014; Singh *et al.*, 2016).

Klebsiella oxytoca is a non-motile, gram-negative rod-shaped bacterium belonging to the family *Enterobacteriaceae*. *K. oxytoca* is ubiquitous in the environment (Gokiewicz, 2009) and can be cultured from the skin, mucous membranes, oropharynx and intestines of healthy humans and animals, as well as a variety of tissues from clinically affected humans and animals has been reported to exhibit multiple antibiotics resistance which also makes it a microorganism of public health concern.

Their presence in the commercial samples may be attributed to the poor hygiene condition in which the products are made (Utermann, 1998). These include the source of bottles used in packaging Nunu, the source of water for processing and storage methods. If not stored properly, dairy products provide a good environment for microbial proliferation.

Serratia spp. are Gram-negative bacteria that are similar in structure to *Escherichia coli and Klebsiella* spp., yet the treatment and control of these organisms remain difficult. The most common mastitis-causing species is *Serratia marcescens*. However, the treatment and

control of these organisms is similar across all species of Serratia.

Pseudomonas has been identified as a predominant milk-associated psychrotrophic bacteria, making it one of the most important bacterial groups in the dairy industry (Wiedmann *et al.*, 2000; Marchand *et al.*, 2009a). The most commonly detected *Pseudomonas* species in milk and milk products are *P. fluorescens, P. gessardii, P. fragi*, and *P. lundensis* (Mallet *et al.*, 2012). Several bacteria genera have been described as psychrotolerant microorganisms and *Pseudomonas* is the genus of most technological relevance (Hantsis-Zacharov and Halpern 2007). Since psychrotolerant microorganisms are commonly found in natural environment, dairy products can be contaminated by contact with water, the inner surface of bulk tanks during storage of refrigerated raw milk, surface of cows' teats and equipment used throughout the milking process (Leriche *et al.*, 2004, Fagundes *et al.*, 2006, Teh *et al.*, 2011). Therefore, the adoption of hygienic measures during milking process is necessary to reduce contamination with psychrotolerant microorganisms (Elmoslemany *et al.*, 2010).

Table 3. Isolates Characterized Using Molecular Genomic Technique

Code	Identification	Strain	E-value	Percentage	Accession Number
TT 1	*Serratia surfactantfaciens*	YD25	0.0	96.45 %	NZ_CP016948.1
TT 2	*Enterobacter soli*		0.0	95.71 %	NC_015968.1
TT 3	*Klebsiella oxytoca*	10-5243	7x 10-120	82.79 %	NZ_JH603144.1
TT 4	*Pseudomonas inefficax*	JV551A3	5x 10-169	89.20 %	NZ_OPYN01000207.1
TT 5	*Salmonella bongori*	85-0051	5x 10-24	80.62 %	NZ_CP053416.1

Key: TT1 – Milk Products 1, TT2 – Milk Products 2, TT3 – Milk Products 3, TT4 – Milk Products 4, TT5 – Milk products 5

Enterobacter soli is an important source of food-borne pathogens. These pathogens in milk have been linked to the environment on the farm, mixing clean milk with mastitis milk and from livestock (Marco *et al*., 2008). E. *coli* frequently contaminates food organisms and it is a good indicator of faecal pollution (Benkerroun *et al.*, 2004). The presence of E. *coli* in milk products indicates the presence of pathogenic microorganisms, which constitute a public health hazard (Yohannes, 2018). E. *coli* is among many pathogenic microorganisms which can access to milk and some of dairy products which is considered a reliable indicator of contamination by manure, soil and contaminated water (Somroo *et al.*, 2002). This shows that microorganisms including *Proteus* sp., *Pseudomonas aeruginosa, Pseudomonas* sp., *Escherichia coli, Staphylococcus aureus, Staphylococcus* sp., *Streptococcus* sp., *Enterobacter* sp., *Aeromonas* sp., *Bacillus* sp., *Bacillus subtilis, Klebsiella pneumoniae* and *Serratia* sp. were isolated from the samples.

CONCLUSION

This study evaluated the nutrition and safety of milk products (Wara and Nunu) sold in Ilorin; all the milk product samples contained pathogenic bacteria in high quantities which may pose a great danger to the consumer of these ready-to-eat products. There is therefore need to develop standard for the producers and handler to prevent contamination.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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Crop Residues Potential Reclamation of Irrigated Saline Ground Water, Sudan

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ABSTRACT

Reclamation of ground saline water is a challenge and crucial for agricultural development in the Sudan, especially for artificially irrigated areas that are away from the river Nile and its tributaries. This study aimed to investigate the reclamation potential of crop residues for saline groundwater. Three crop residues of wheat, date palm and groundnut crops were tested as filters in this study. Three filter types from each plant residue were prepared by oven drying at 170 C°; muffle furnace at 250 -300C°; and treated the crude fibre from the furnace at 250-300 C° with 1.25% sodium hydroxide for 30 minutes. PVC plastic pipes of different sizes were filled with the three prepared filter types. The oven-dried residues were put in the 20 cm long and 5 cm diameter plastic pipes while the muffle furnace-dried residues and treated crude fiber were put in 10cm long and 2cm diameter plastic pipes. Constant volumes (100 ml) of saline water were passed through the various filters in the PVC pipes, the leachates were collected, and their salinities were measured using electrical conductivity Apparatus. This procedure of saline water addition and measurement of EC for leachate was repeated ten times. Two saline groundwater from Hattab area-Khartoum North (10 dSm^{-1}) and Soba area-Khartoum (3.0 $dS\ m^{-1}$) were passed on filter PVC columns of different diameters filled with the selected residues and their crude fibres. Successive 10 additions of 100 ml saline water from the two waters were filtered through the columns and the electrical conductivity (EC) of the leachates was determined. The results indicated that the EC of leachate from different treatments increased at the beginning and then decreased at an additional 5. Wheat straw and date palm showed comparatively remarked reclamation potential and chemical stability in comparison to groundnut peals. After addition 5, the EC of leachate started to increase again, this indicated the span life filters from these residues. This study shows that crop residues, as waste and low-cost materials, are economically and environmentally feasible reclamation materials of saline water in developing countries for agricultural and drinking uses.
Keywords: Crop residue, saline groundwater and crude fibre.

INTRODUCTION

Globally, fresh water is very scarce (0.75%) and the remaining percentages are saline water (97%) and glacier (2.25%). Arid and semi-arid regions have significant eco-agricultural potential (Soifer, 1987), but they suffered from water shortage and high salinity of their ground due to low recharge and high variability (Simmers, 2002). Around 17% of the world's cropland is irrigated and contributed by more than a third of the food and fiber (Hillel, 2002 .) Saline water in dry land harms crop production. The population pressure enforces farmers in these regions to use saline water in irrigation for food production (Babaiyan & Ziatabar, 2002) on the other hand, climate change, agricultural production, and biofuel production will increase water needs in the future.

Sudan's economy heavily relies on agriculture as the main livelihood option for more than 60% of its population especially in rural areas (Elgali *et al.*, 2010). Sudan is covered by main four aquifers, namely: Nubian sandstone aquifers (28%) with good water quality and approximate recharge of 1000 million m3/Y (SNCIHP, 2000), The Um Rawaba aquifers (7%) with annual recharge of 600 to 150 million m3/Y and statistic water level of 10-150 and The alluvial aquifer compromise local important basins that have good water quality with a total annual recharge of 375 M m3 and shallow water table (Abdo & Salih, 2012). Sudan relies on groundwater aquifers, for domestic uses, agricultural production and livestock (Wheater ., 2007; Omer , 2013). Currently, heavy abstraction of groundwater for agriculture is practised in the Northern Sudan States and Khartoum State (Mukhtar, 2008).

Several desalination technologies are applied; however, the most popular ones are multi-effect distillation

(MED), multi-stage flash (MSF), and reverse osmosis (RO) (Bart & Carlo, 2002). Thermal desalination techniques collect pure by evaporation process (Nollet, 1748; Kravath & Davis, 1975; Stache, 1989). Recent techniques use activated carbon that is produced from the physical and chemical processes, chemical process involves impregnation of the precursor with chemical activating agents such as H_3PO_4 followed by pyrolysis at low temperatures. The physical process is achieved by heating at 500 to 900C in an inert atmosphere followed by mild oxidation air stream or carbon dioxide (Rodriguez-Reinoso & Molina-Sabio, 1992)Active carbon is the most adsorbent material to remove heavy metal. but still, it is produced in an uneconomic way and cannot be recycled (Othman *et al*, 2010). In the last decades adsorption process has involved the use of activated carbon to purify and separate pollutants from wastewater (Ali, 2010).

The adsorption process is a surface phenomenon it is depends on the number of sites available, porosity, and specific surface area of adsorbents (Ahmed *et al*, 2010). Adsorption capacities of carbon depend on sources of raw material (Erol & Numan, 2005).The mechanism of adsorption depends on the physical and chemical characteristics of adsorbents and the mass transfer process (Danish *et al*, 2011). Absorption of materials for the reclamation of wastewater and saline water was widely used and practised, however, they were very expensive. Agricultural waste contains mainly lignin and cellulose as the main constituents (Sud *et al*, 2008). Other components are hemicelluloses, lipids, proteins, simple sugars, starches, water, hydrocarbons, ash and many more compounds including a variety of functional groups found in the binding process, for example, carboxyl, amino, alcohol and esters (Beveridge & Murray, 1980; Gupta & Ali, 2000). The date palm leaves have a surface area of 525m2/g (Alaya *et a*l, 2000). Lignocellulosic materials of date palm consist of cellulose, hemicellulose, and lignin in the range of 40–50%, 20–35%, and 15–35%, respectively (Macedo, et al., 2008)

(Danish *et al*, 2011) Used active date bead (ADB) with $ZnCl_2$ to remove lead from groundwater and recorded that the maximum adsorption capacity of ADB was 76.92 mg/g at 318.2 K and pH 6.5. (Jibril et al, 2008), Used date palm stem treated with KOH and H_3PO_4 and heating. (Girigs & El-Hendawy, 2002)Found that at low temperatures better adsorption material was observed. (El Nmer *et al*, 2008) found that the optimum pH value (Riah*i et al*., 2008) used filter fibre date palm filtration to treat wastewaters and showed a good ability to remove turbidity, COD, phosphorus and helminth eggs. Wheat bran treated with sulfuric acid to prepare active carbon has a good surface area to adsorb copper ions at pH five (Ozer, *et al*., 2004). (Ozer & Pirincci, 2006) Removed lead ion by wheat bran treated with H_3PO_4 and found that the maximum removal rates (82.8%) were at pH six after two hours of contact time.

(Basci, et al., 2004))recorded that wheat shells and carbonized coir pith had high efficiency for sequestering copper metal. The utilization of rice and wheat bran was less effective when used as adsorbent materials (Farajzadeh & Moji, 2004; Gupta, et al., 2007; Oliveria, et al., 2005) stated that wheat husk was an effective material to remove reactofix golden yellow 3 RFN treated with 30% to 60% hydrogen peroxide for 24 hours. Few studies used crop residues in the management of saline water for irrigation (Abd El-Lateef , 2010). In Sudan, salinity in water coupled with soil salinity hinders the agricultural productivity of various lands especially in the Northern and Khartoum States and many projects and farms transform their projects into other activities. Moreover, very little research was conducted in the desalinization of saline water, particularly with use of plant materials as adsorbent materials to reduce salinity. Therefore, the main objective of this research is an assessment of the reclamation potential of three plant residues as environment-friendly and low-cost adsorbent materials for saline groundwater.

MATERIALS AND METHODS

Study area

The study area consists of Soba research station (Latitude 15° 24' and 15° 30' N and longitude32° 32' and 32° 28' E) in Soba east and Hattab area (15° 42'.8.N 32° 41' E) in northern Khartoum, Khartoum state.

Two saline groundwater samples were collected from Soba research station that with relatively low conductivity (EC of 3.65 dS/m) and the Hattab area with very high conductivity (EC of 10.45 dS/m). Three types of plants residue were used namely: Wheat Stem (WS), Date Palm Leaves (DPL) and Groundnut Peel (GNP). Wheat stem and date palm leaf residues were collected from the Khartoum University demonstration farm and the groundnut peel residues were collected from the central market at Shambat, Khartoum North Sudan.

Three filter types from each plant residue were prepared by subjecting the plant residues according to (AOCA, 2000) into three physical and chemical treatments; namely: drying by oven at 170 C°; drying by muffle furnace at 250 -300 C° to remove organic compounds and drying by a furnace at 250-300 C° and addition of 1.25% sodium hydroxide (1.25% NaOH) to crude fibre for 30 minutes. PVC plastic pipes of different sizes were filled with the treated plant residues as filtering materials. The oven-dried residues were put in the 20 cm long and 5 cm diameter plastic pipes while the muffle furnace-dried residues and treated crude fiber were put in 10cm long and 2cm diameter plastic pipes. Constant volumes (100 ml) of saline water were passed through the various filters in the PVC pipes, the leachates were collected, and their salinities were measured using electrical conductivity Apparatus. This procedure of saline water addition and measurement of EC for leachate was repeated ten times.

RESULTS AND DISCUSSIONS

The results indicated that for the three crop residues and treatments, the salinity of the first leachate was increased and then decreased after subsequent additions, however, at a certain addition the salinity started to increase again

Effect of oven-dried crop residues on Hattab Water Salinity

For oven-dried, salinities of leachate were increased at the first addition and then decreased to 8.8, 9.6, and 9.3dS/m at the ninth addition for wheat stem, date palm leaves and groundnut peel, respectively. The EC decreased with addition up to the 10th addition for wheat stem and date palm leaves but increased to 10.23 dSm-1 for groundnut peel. Date palm leaves and groundnut peel were recorded with similar values in the middle additions. The higher value (17.3dS/m) was observed at first addition in the wheat stem, then started to decrease. Date palm and Wheat stem leaves were stable chemically and the last one was recorded, however, the wheat stem showed the lowest value (8.6 dS/m). Threshold addition that showed a decrease of EC was at T3 for wheat stem and groundnut and T5 for date palm leaves. These results are consistent with (Basci, et al., 2004)) , who reported that wheat straw and carbonized coir pith have high efficiency for capturing copper metal. It is also agreed with (Idris, et al., 2012) , who stated that activated carbon from groundnut was effective for the removal of Cr and Ni from dye effluent. This procedure of saline water addition and measurement of EC for leachate was repeated ten times.

Table 1. Effect of oven-dried crops residues on Hattab water salinity

Times of addition	Wheat stem ECw (dS/m)	Date palm leaves ECw (dS/m)	Groundnut peel ECw (dS/m)
T0	10.5	10.5	10.5
T1	15.6	17.3	11.7
T2	11.2	10.6	10.8
T3	9.7	10.2	9.6
T4	9.1	10.1	9.8
T5	8.8	9.9	9.7
T6	8.9	9.9	9.9
T7	9.1	9.6	9.5
T8	8.8	9.6	9.5
T9	8.8	9.6	9.3
T10	8.6	9.7	10.2

In this table and the following ones, these abbreviations are described as follows:

T0 first addition, T1, T2, T3….T10 successive additions, in each addition100 ml of saline groundwater, was added.

Effect of furnace-dried crop residues on Hattab water salinity

A similar pattern to the previous treatment was observed and at 10th additions, 9.6 dropped the EC. Percentage, 12% and 9.1% for wheat stem, date palm leaves and groundnut peel, respectively. The lowest values of 8.4dS/m, 9.2dS/m and 9.1dS/m were recorded after the 7th addition for wheat stem, date palm leaves and groundnut peel respectively. In this treatment, all plant residue showed good chemical stability and the electrical conductivity decreased gradually. Wheat stem recorded a higher value (16.7dS/m) in initial addition, and a lower value (8.4dS/m) at addition (T10). The threshold addition that showed a decrease in EC of all plant residue was T5. This finding agreed with five (Ozer, et al., 2004) who stated that active carbon prepared from wheat bran treated with sulfuric acid adsorbed copper ions. In addition, (Gupta, et al., 2007) supported this finding and stated that wheat husk was an effective material to remove react fix golden yellow 3 RFN treated with hydrogen peroxide 30% at 60% for 24 hours. Ground nut peel revealed an increase again this indicated that the critical phase to remove or renew the residue was at 9 leaching phase, Perhaps that led to the degree of heating ($300C^0$) not being enough to remove the organic compound.

Table 2. Effect of furnace-dried crop residues on Hattab water salinity

Times of addition	Wheat stem ECw (dS/m)	Date palm leaves ECw (dS/m)	Groundnut peel ECw (dS/m)
T_0	10.5	10.5	10.5
T_1	16.7	12.5	15.5
T_2	12.7	11.6	11.6
T_3	10.8	10.7	10.9
T_4	10.2	10.4	10.1
T_5	9.9	9.5	9.1
T_6	9.6	9.3	9.5
T_7	9.1	9.3	9.1
T_8	9.2	9.9	9.5
T9	9.5	9.6	9.6
T10	8.4	9.2	9.5

Effect of crude fibres on Hattab saline water

The crude fibre of plant materials exhibited a similar effect to furnace-dried materials (Table 2). Generally, the EC value tended to decrease after the 4th addition. Wheat stem recorded higher values (16.70dS/m), and lower values (8.40dS/m) of Electrical conductivity. All plant residues have good chemical stability and limited effect on water salinity. Threshold addition appeared at T5. That meant crude fibres were not significant in reducing high levels of saline water. This agreed with (Farajzadeh & Moji, 2004) (Oliveria, et al., 2005) (Gupta, et al., 2007)) who reported that the utilization of

rice bran and wheat bran as an adsorbent is less effective as only 50% removal efficiency.

Table 3. Effect of crude fibers on Hattab saline water

Times of addition	Wheat stem ECw dS/m)	Date palm leaves ECw (dS/m)	Groundnut peel ECw (dS/m)
T0	10.5	10.5	10.5
T1	16.7	12.5	15.5
T2	12.9	11.6	11.6
T3	10.8	10.7	11.1
T4	10.2	10.6	10.1
T_5	9.9	9.5	9.2
T_6	9.8	9.3	9.5
T_7	9.1	9.3	9.3
T_8	9.2	9.9	9.5
T9	9.5	9.6	9.6
T10	8.4	9.2	9.5

As in the case of Hattab, salinity was raised up at the beginning and then decreased after subsequent additions, however, at a certain level of salinity started to increase again

Effect of oven-dried crops residues on Soba Water salinity

The EC value of leachates from soba water increased with the additions until the third addition for wheat stem and decreased in the subsequent additions. For date palm leaves, the EC values increased sharply to the value of 17.03 **dS/m** after the first addition and then decreased. A similar trend was observed for groundnut peal, but after the ninth addition was still higher than the original value **(Table 4).** Date palm leaves reached the highest value (17.03dS/m) at the first addition, whereas wheat stem produced the lowest value (2.73dS/m) at addition 8 and has good chemical stability. Threshold addition appeared at T4 and T8 for wheat stem and date palm leaves, respectively, while Groundnut peel failed to decrease the EC of Soba water and the final one was greater than the original EC. Wheat stem showed consistent and good decreasing of EC, which indicated good bio adsorbents properties at this level of salinity. These results agreed with (Ozer & Pirincci, 2006) who concluded that wheat bran treated with H_3PO_4, had maximum removal rates (82.8%) at pH =6 after two hours of contact time. Date palm leaves have a narrow capacity to trap salts.

Effect of furnace dried crop residues on Soba water salinity

Wheat stem and groundnut peel showed good capacity to adsorb salts and are chemically stable. Date palm leaves recorded high value (12.86 dS/m) at T1 addition, and wheat stem showed lowest value (2.70dS/m) at T9 addition. All plants residue adsorbed salts and decreased original EC at 10th addition. Threshold addition appeared at T2, T4 and T3 for wheat stem, date palm leaves and groundnut peel, respectively (Boumchita, et al., 2017) recorded similar pattern and indicated that peanut shell was low-cost adsorbents material to remove Eriochrome black T (EBT) dye from solution. This was in line with (Xiano-Kun, et al., 2014)who revealed that the peanut shell was effective and economical bio sorbents to removal heavy metals from aqueous solution that containing aminoacids and sodium chloride.

Table 4. Effect of oven dried crops residues on Soba water salinity

Times of addition	Wheat stem ECw (dS/m)	Date palm leaves ECw (dS/m)	Groundnut peel ECw (dS/m)
T_0	3.65	3.65	3.65
T_1	4.86	17.03	6.83
T_2	6.13	11.16	6.63
T_3	4.10	8.3	5.2
T_4	2.96	7.76	4.43
T_5	3.16	6.53	4.03
T_6	2.76	3.9	3.7
T_7	2.80	4.33	3.86
T_8	2.73	3.1	3.83
T_9	2.86	2.96	3.7
T_{10}	2.76	3	3.63

Table 5. Effect of furnace dried crop residues on Soba water salinity

Addition	Wheat stem ECw (dS/m)	Date palm leaves ECw (dS/m)	Groundnut peel ECw (dS/m)
T_0	3.65	3.65	3.65
T_1	7.70	12.86	6.5
T_2	3.30	11.46	3.83
T_3	3.03	7.63	3.1
T_4	3	3.10	3.1
T_5	2.96	2.96	2.96
T_6	2.83	3.20	2.96
T_7	2.70	3.20	3.20
T_8	2.66	2.83	2.83
T_9	2.76	2.80	2.80
T_{10}	2.80	2.93	2.80

Effect of crude fibers on Soba saline water

As the previous treatments, at the beginning EC increased and then decreased with continuous additions (Table 6). The percentage decrease in salinity at the 10 addition was 25%, 23% and 17% for wheat stem, date palm leaves and groundnut peel respectively. The lowest value was observed at T3 for groundnut peal and at T10 for wheat stem. Threshold addition appeared at T4 for wheat stem and T3 for date palm leaves and groundnut peel, respectively. Wheat stem and date palm leaves showed chemical stability while groundnut was unstable. This finding agreed with (Riahi, et al., 2008) who stated that date-palm fibers filtration was an efficient method

to economically remove turbidity, phosphorus, and organic materials in terms of COD and helminth eggs of secondary domestic wastewater from an activated sludge treatment process.

Table 6. Effect of crude fibres on Soba saline water

Times of addition	Wheat stem ECw (dS/m)	Date palm leaves ECw (dS/m)	Groundnut peel ECw (dS/m)
T_0	3.65	3.65	3.65
T_1	6.25	7.66	7.66
T_2	4.83	3.50	4.23
T_3	3.83	3.06	2.8
T_4	3.26	3.03	3.06
T_5	3.16	3.10	3.03
T_6	2.96	2.86	3.06
T_7	2.96	2.90	2.93
T8	2.83	2.83	2.83
T9	2.76	2.83	3
T10	2.73	2.80	3

Comparative Analysis of Performance for oven dried residues at two levels of water salinity

The results showed that, wheat steam was a good bio-sorbents material, and have high capacity to trap salts at both level of salinity. Date palm leaves performed well at high salinity level of Hattab compared to the relatively low salinity level of Soba water (3.65dS/m). Groundnut peel had low capacity to adsorb salts at both salinity levels.

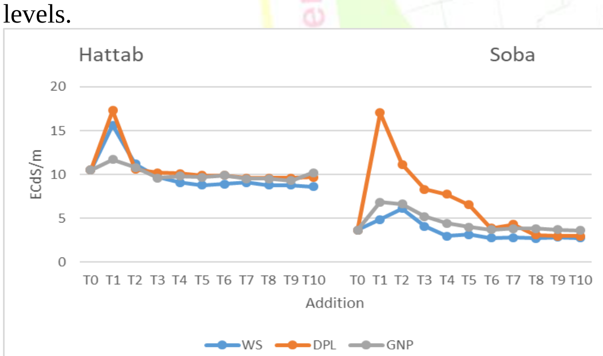

Figure 1: Effect of oven-dried plant residues on water salinity at two salinity level

Comparison of furnace-dried residues performance at two levels of water salinity

As in case of oven dried, wheat steam showed, have high capacity to trap salts at both level of salinity. Similar pattern was noticed by date palm which reduced water salinity at two sample of ground saline water (10.45 and 3.65dS /m), however, at the and addition showed a very high salinity. In contrast, groundnut peel relatively reduced the salinity of low-level saline water of Soba sample compared to Hattab sample.

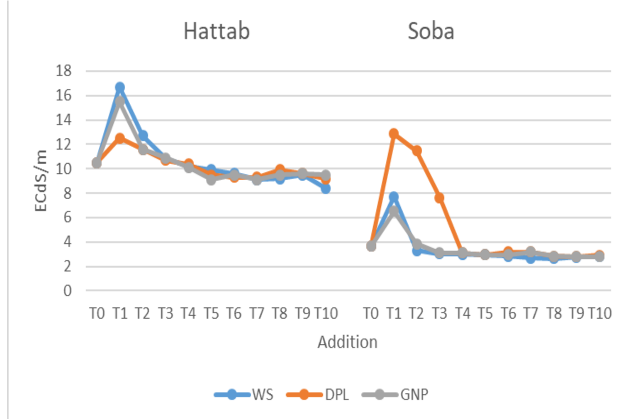

Figure 2: Effect of furnace-dried plant residues on water salinity at two salinity levels

Comparative Analysis of performance for crude fiber residues at two levels of water salinity

Wheat steam showed a high capacity to trap salts at both levels of salinity. Date palm leaves recorded good response at both level of salinity but at Soba sample showed recorded better results compare to the Hattab sample. Groundnut peel had a narrow capacity to trap salt, especially at Soba.

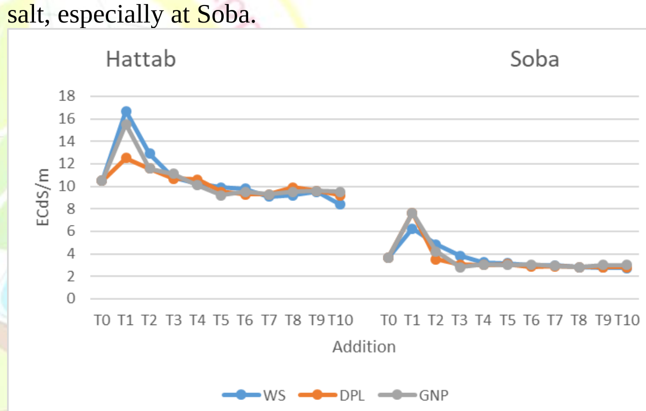

Figure 3: Effect of furnace-dried plant residues on water salinity at two salinity levels

CONCLUSION

The study attempted to investigate the use of raw and treated plant residues as low-cost adsorbent materials to remedy saline water from two areas in Khartoum. The study used residues of wheat, date palm and groundnut peals. The study concluded the Plant residues with different treatments efficiently reduced the water salinity at a certain point and then saturated with ions. The Threshold point for the different plant residues was noticed to be at addition 5. Treatment of residues with a muffle furnace and converted to crude fibre improve the capacity of these residues to trap salts from saline water. Use of plant residues as bio-sorption materials to reclaim saline water. They are relatively cheap, easily available and renewable. Use of wheat stems and date palm leaves for reducing salts of saline water. Physical treatment of plant residues with oven and muffle furnace to improve its adsorbing potential. Finally, further, in-depth research is recommended to test the sorbent capacity of these

materials at the industrial level. This includes the quantity of residue, length and diameter of the columns.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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Status of Fish Health Management Practices Adopted by Fish Growers In Badhaiyataal Rural Municipality, Bardiya, Nepal

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ABSTRACT
This study was conducted in Bardiya's PMAMP Fish Zone (Badhaiyataal rural municipality) to study the current fish health management practices adopted by fish growers. During the research period, 50 randomly selected fish farmer households were surveyed using structured questionnaires. The majority (80%) of the fish growers were male, averaging 45 years old with 13 years of farming experience. Most of them were literate (76%), practicing poly-culture fish farming focused on major carps with underground water as the main source of water. Training received respondents were dominated oversampled population. Argulosis, ulcer disease and asphyxiation were major diseases seen in the fish grower's farm at the study site. Most of the respondents used lime, maintained an optimum stocking rate, and selected healthy fingerlings, and pond drying as preventive measures. Most of the respondents followed biosecurity measures such as monitoring fish, avoiding contaminated feed, controlling of water source and sterilization of net by sun drying. The unavailability of diagnostic laboratories, lack of skilled technicians, advisory services from organizations and knowledge of disease and treatment were the major problems faced by farmers in curing the disease. Among these, the unavailability of a diagnostic laboratory was found to have caused severe impact. According to the research findings, the establishment of a training and diagnostic laboratory in the area will be essential for enhancing fish health and raising production as it would enable rapid disease identification and give local farmers the skills and information they need.
Keywords: Fish Health, Biosecurity, Fish diseases, Preventive measures, Aquaculture.

INTRODUCTION
Nepal is the second-richest country in terms of natural resources and has a lot of potential for water resources. Water resources account for approximately 2.6% of Nepal's total land area (MoALD, 2020), and its natural landscape is diverse. The fishes not only contribute to the local diet but are also good sources of animal protein, amino acids, folic acid, omega-3 fatty acids, and many more (Philibert et al., 2013). Besides the nutritional value, aquaculture has contributed 1.13% to the national gross domestic product, while 4.18% to the agricultural gross development product (AGDP) and per capita production of fish was found to be 3.11 kg (CFPCC, 2019). However, alongside these successes, challenges can be seen in fish health due to intensive fish farming practices. Studies showed that almost 50% of production loss is due to diseases that are more severe in developing countries (Leung & Bates, 2012) and 25 to 30% is estimated loss in Nepal due to diseases (MoALD, 2020). Fish diseases refer to any condition that adversely affects the health of fish, and can be caused by environmental stressors, genetic factors, or pathogens, which are broadly classified into infectious and non-infectious diseases, with gram-negative bacteria being a common cause of bacterial infections (Jeney, 2017). In Nepal, there are different parasitic, bacterial and fungal diseases found in fish, and EUS was identified as the prevailing bacterial-fungal ailment that greatly affected common carp fish in areas such as Trishuli, Begnas, and Mirmi. Meanwhile, the incidence of coccidiosis, attributed to *Eimeria spp*, has been observed to be on the rise in rainbow trout aquaculture (Shrestha et al., 2019). In Nepal, EUS is highly prevalent in fish ponds due to rapid fluctuation of temperature, limited or no exchange of water and poor application of liming material (Baidya & Prasad, 2013). During the winter season, there were increased reports of fin rot, which predominantly impacted common carp, silver carp, and bighead carp in Nepal (Shrestha et al., 2019).
Fish illnesses due to bacteria are common and among the toughest health problems to cure, and frequently seen in eggs, fry and fingerlings, and cause huge mortality in fish (Sandeep, 2016). Other bacterial diseases seen in

fish are Dropsy, Vibriosis, Columnaris, and Furunculosis. The most common reason for parasite infections in fish is protozoa, which are minute organisms that reside in aquatic environments that commonly affect the skin and gills of fish often leading discomfort, weight loss, and sometimes death, and chemicals like formalin, potassium permanganate, and copper sulfate are often utilized for therapeutics (Francis-Floyd, 2005). White Spot disease/Ich disease, Trichodinasis, Whirling disease, Gyrodactylosis and Dactylogyrosis are some examples of parasitic diseases found in fish. Fish aquaculture can be severely affected by non-infectious diseases, which are frequently due to environmental, genetic, or dietary causes. The primary causes are environmental problems such as high ammonia, low oxygen, and pollutants (Francis-Floyd, 2005).

Fish disease incidence in Nepal was first reported in 1965, with overcrowded ponds leading to up to 65% fry mortality (Jha & Bhujel, 2012). Environmental factors, parasites, and poor management contribute to high mortality rates (Bista et al., 2001). In central Terai, high disease prevalence is due to overcrowding and poor management, while the western Terai has fewer issues due to better pond systems, farmer education, and effective practices (Jha & Wagle, 2016).

Fish health management in aquaculture refers to the set of practices aimed at averting fish diseases (Kyule-Muendo et al., 2022). Once fish become diseased, it can be challenging to rescue them. Therefore, effective fish health management entails preventing diseases instead of treating them (Francis-Floyd, 2005). The study conducted by Mandal & Paudel (2019) found that dipping fish in 2-3% salt solution for 5-10 minutes and dipping in a solution containing 500 parts per million of copper sulfate for one minute daily was found to be an effective method for curing Argulosis and fungal infection, respectively in fish cultured in the ponds of Begnas. A combination of lime and potassium permanganate was commonly used for disease treatment, although some farmers used only lime or a mixture of lime and salt (Faruk et al., 2004). To effectively prevent diseases and early diagnosis of health issues, routine health monitoring of farmed fish is essential. Apply Salt @ 200 - 300 Kg/ 0.16 ha when water becomes heavily polluted and a mixture of 500g KMn04 with 60 - 80 Kg lime spray all over the water surface of 0.16 ha for controlling EUS (Das & Das, 2015). To eliminate *Ichthyophthirius multifiliis* (Ich) in catfish fingerlings, Formalin (25mg/L) and Malachite green is found to be effective chemicals (Tieman & Goodwin, 2001).

Fish farming in Bardiya district is now a popular business, as a result, the proximity of ponds can be seen so that various pathogens could be transmitted to the healthy pond through multiple means such as birds, and different utensils. Trained and skilled manpower is lacking in the research site and those who are available are required to perform a wide range of duties that increase workloads and lower quality work, potentially increasing risks to fish health. This might have negative consequences, including an increased risk of disease outbreaks that could have a significant impact on the health of fish populations and the livelihoods of those who depend on them. The research site is deprived of adequate quarantine services, information regarding fish disease and management practices, and diagnostic laboratories. This research will look closely at how the farmers take care of their fish ponds and give them better advice to keep their fish healthy. The objectives of this research is to investigate fish health management practices adopted by fish growers and the problems in health management practices.

MATERIALS AND METHODS

Research Site

The research was conducted in Badhaiyataal Rural Municipality of Bardiya district, Nepal. This municipality was selected due to the large number of fish farmers reside in this area. It ranges in altitude from 143 to 157 meters above sea level and has an area of 115.19 square kilometers.

Figure 1. Map of Nepal showing research Site

Two types of data were collected for this research, primary and secondary data. Primary data was collected through the help of face-to-face interviews with the individual respondents. A structured questionnaire was made for collecting data, and recorded in Excel. Secondary data was retrieved through publication from various reputable institutions such as the Agriculture Knowledge Center (AKC) Bardiya, Agriculture Information and Communication Centre (AICC), Central Bureau of Statistics (CBS), Nepal Agriculture Research Council (NARC), and the Prime Minister Agriculture Modernization Project (PMAMP).

Sampling

The total number of fish farmers in the Badhaiyataal rural municipality was computed, resulting in a count of 55 farms and calculated sampling size with the help of the Taro Yamen formula with a 95% confidence level.

$$n = \frac{N}{1+Ne^2}$$

Where,

n = number of samples,

N = number of population

e = allowable error

Having calculated the sample size with the help of the above-mentioned formula, 50 farmers were selected using a simple random sampling method. Before being interviewed, a preliminary questionnaire was prepared to identify questions that may pose difficulties for the respondents, evaluate the questionnaire's applicability and clarity, and adjust it to the conditions on-site. After that survey was conducted from April to May 2023 through face-to-face interviews with farmers.

Data Analysis

After the collected data was entered and cleaned through MS Excel, it was analyzed in Statistical Package for Social Sciences. Descriptive analysis was done for socio-demographics and farming systems such as age, gender, level of schooling, occupation, farming experiences, source of fingerlings and water, Training and so on, whereas forced ranking technique was used for ranking problems and reason for fish mortality using formula:

$$\mathrm{I} = \sum \frac{S1F1}{N} \qquad (Miah, 1993)$$

Where,
I = Index value
$\sum$ = Summation
Si = Ith scale value
Fi = Frequency of ith importance given by the respondents
N = Total number of the respondents

RESULTS AND DISCUSSIONS

Age, Area of pond and Farming Experiences

The age range of the 50 respondents was ranges from 28 to 65 years, with an average age of 45 years. The respondents had varying degrees of farming experience, ranging from 1 to 23 years with an average of 13 years, and the area of the pond varies from 0.07 to 7.34 ha, with an average area of 1.2380 ha. This data is illustrated in Table 1.

Table 1. Age, Area of Pond, Farming Experience

Items	Mean	Minimum	Maximum	Std. Deviation
Age (Year)	45.84	28	65	10.249
Area of Pond (ha)	1.2380	0.07	7.34	1.34421
Farming Experience (year)	13.70	1	23	6.944

Gender, Religion and Education

Out of the sampled population, the majority of the respondents were male, accounting for 80% (n=40), whereas only 20% (n=10) were females, illustrated in Figure 2. Most of the fish farmers were Hindus, which comprise 92%, followed by Muslims 6%, and Buddhists only 2%, the data is illustrated in Figure 3. The majority of the farmers were educated where 32% had been educated up to at least Higher Secondary school which was followed by 30% having School Education Examination (SEE) and 10% being below SEE. Only 4% were educated up to graduation level and 24 % were illiterate. The data on education is depicted in Figure 4.

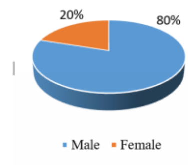

Figure 2: Gender of Respondent

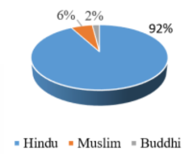

Figure 3: Religion of Respondent

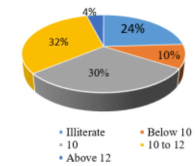

Figure 4: Education of Respondent

Farming System, Procurement of fingerlings, and Training

Out of the total respondents, only one individual practised monoculture of Pangas species as their farming system whereas the majority followed polyculture of Carp species such as Rohu, Naini, Common Carp, Silver Carp, Grass Carp, Bighead Carp, and Bhakur. This suggests that the majority of respondents have good knowledge about the proper use of various levels of water. Similarly, 74% (n=37) said that they had acquired fingerlings from government farms whereas 24% (n=12) used both government farms and private nurseries/hatcheries as their sources of fingerlings. However, only 2% relied solely on private nurseries or hatcheries. Likewise, 66% (n=33) had attended fish farming training, while 34% (n=17) had not received such training. The data about the Farming system, procurement of fingerlings and training are illustrated in Figure 5, 6, and 7 respectively.

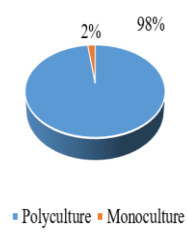

Figure 5: Farming System

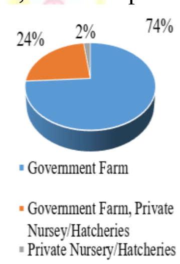

Figure 6: Procurement of fingerlings

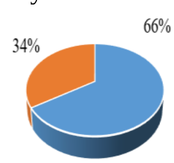

Figure 7: Training

Mode of Fishing and Main Source of Water

Figure 8 shows the result of the mode of fishing in which a significant proportion of participants, comprising 86% (n=43), reported that they were full-time fishing. This indicates fishing is the main source of income for a significant portion of the community. Nevertheless, 14% of respondents (n=7) stated that they fished as a hobby on the side. On the other hand, the distribution of main source of water to the pond is described in Figure 9, where most of the respondents used underground water to their ponds using boring, which accounts for 67%, followed by monsoon water (16%) and submersible pump water (12%). However, only a small percentage of respondents (4%) reported using lake water in their pond. Same result was found in the research conducted by Yadav et al. (2023) reveled that fish farms were found to use water from various sources, such as deep boring, shallow tube wells, and rivers/canals.

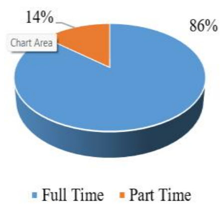

Figure 8: Main Source of Water

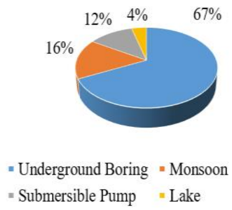

Figure 9: Mode of Fishing

Information about fish disease

The variables of fish disease information is illustrated in Table 2 along with frequency and percentage.

1. Fish Disease

The majority of the respondents revealed that their ponds were affected by Asphyxiation, a non-infectious disease due to lack of oxygen in the ponds that results devastating fish death in their pond. Similarly, Argulosis was another important infectious disease seen in the pond followed by ulcer. Shrestha et al. (2019) also found that Argulosis, caused by the parasite Argulus, was a common disease in Indian major carp, particularly among brood fish which was problematic in locations such as Mirmi and Syangja. Likewise, Yadav et al. (2023) reported that Argulosis was the most prevalent disease in the Dhanusha district whereas asphyxiation caused the highest mortality.

2. Disease Reported in Farm

When respondents were asked whether they had a disease problem in their pond, 64% of the respondents (n=32) said that they had a disease problem during the last year, while only 6 farmers said that they didn't have a disease problem in their pond to date. Interestingly, 10% of the farmers were recently observed the diseased, which suggests that there may still be ongoing health issues on the farm. This result is supported by Frauk's (2008) study in which the majority of farmers said that they had fish health problems during the previous year and few farmers said that they did not find any disease in their pond.

3. Importance of disease to the respondents

The most commonly reported perception was a moderate problem, accounting for 42% of the responses (n=21). Following that, a minor problem was reported by 26% of the farmers (n=13). On the other hand, 18% of the respondents (n=9) considered fish diseases to be a major problem. Lastly, 14% of the farmers (n=7) reported that fish diseases were not a problem for them. The same result was found in the study of Frauk et al. (2004) in which the majority of fish growers considered fish disease as a moderate problem in Bangladesh.

4. Recognition and knowledge about the cause of disease

Farmers were asked about their ability to identify diseases. A few respondents (26%) reported that they were unable to recognize most of the diseases, while the majority (74%) mentioned being capable of recognizing certain diseases based on specific clinical signs. Similarly, just a small portion of the participants (18%) demonstrated knowledge about the causes of different diseases, whereas the majority (82%) lacked understanding regarding the causes. These results are in line with the study conducted by Aftabuddin et al. (2016) in Bangladesh in which the majority of respondents recognized some diseases whereas few of them were unable to recognize any fish diseases. Similarly, the study conducted by Hasan et al. (2019) also reported that a number of diseases and conditions were recognized clinically by most of the farmers.

5. Fish mortality, and reporting to government office

Most of the respondents (64%) said that they had fish mortality in their farm. Only 36% of the participants' farms reported an absence of disease or mortality. These findings align with Mulei et al. (2021), who also found that most farmers observed fish mortalities on their farms. On the other hand, only 12% of farmer said that they sometimes report to the government office about the outbreak of the disease in their pond and seek advice. While other respondents received advice from fellow fish farmers and agro-vet technicians. Similarly, Jha & Wagle (2016) noted that the level of assistance and reporting of fish diseases to government offices was quite low.

Table 2. Information about Fish Diseases

Variables	Frequency	Percentage
Degree of the importance of disease to the farmer	6	12.0
Not seen		
Recently	5	10.0
6 month ago	6	12.0
1 year ago	32	64.0
Degree of the importance of		
disease to farmer	9	18.0
Major problem	21	42.0
Moderate problem		
Minor problem	13	26.0
Not a problem	7	14.0
Recognition of disease by		
farmer	37	74.0
Yes	13	26.0
No		
Knowledge about the cause of	9	18.0
disease	41	82.0
Yes		
No	32	64.0
Fish Mortality	18	36.0
Yes		
No	6	12.0
Report to government offices	44	88.0
Yes		
No	46	92.0
Disposal of dead fish	1	2.0
Buried in the soil	0	0
Sell them at low price	3	6.0
Consume it		
Don't do anything		

6. Disposal of dead fish

Only 2% of those surveyed sold their unhealthy fish to other people, according to the study, which found that 92% of farmers buried their sick fish in the earth. Remarkably, not a single respondent ate the contaminated fish, and six percent of them did nothing except throw the infected fish into an adjacent canal. Similar findings were reported by Aftabuddin et al. (2016), indicating that sellers were unable to sell diseased fish due to consumer resistance, and the majority of farmers buried their sick fish.

Fish Health Management Practices

1. Preventive Measures

Figure 10 describes about the preventive measures used by the respondents, where almost all respondents apply lime in their ponds, and about 42 of them also dry their ponds as part of their preventive measures. This result is in line with the study conducted by Jha & Wagle (2016) reported that most of the respondents took preventive measures to prevent the outbreak of disease in their pond such as use of lime before disease outbreak, pond drying, and disinfection of equipment. Selection of healthy fingerlings is the second most common preventive measure as they procure fingerlings from government farms and renowned hatcheries, accounts for 44 respondents; however, only 6 farmers did not procure from there, which is quite similar to the findings of the study conducted by Rahman et al. (2022) which showed that 87.5% farmers collected fingerlings from renowned hatcheries. Similarly, 41 respondents maintained the optimum stocking rate for their ponds; in contrast, a similar number of respondents did not only check water before applying in the pond but also test water quality. The number of farmers who have disinfected their equipment and those who haven't accounted for 29 and 21, respectively. Disinfection of farm equipment and culture facilities is routinely included in fish health management schemes in hatcheries (Opiyo et al., 2018).

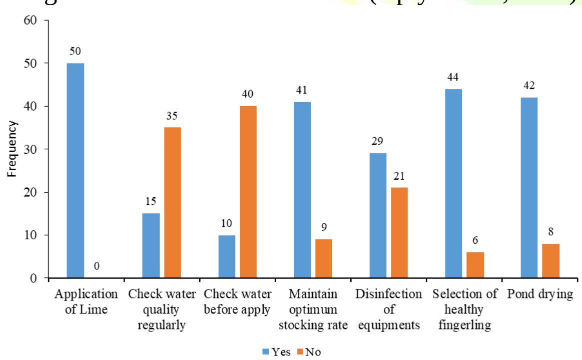

Figure 10: Preventive Measures for Fish Diseases

2. Biosecurity Measures

From figure 11, it was clear that monitoring of fish diseases and avoiding feeding contaminated feed were the most commonly followed biosecurity measures by the same number of respondents (n=48). Disease monitoring is an essential part of any biosecurity program. This consists of regular health evaluations of all stock in a fish nursery. The result from the study conducted by Deb et al. (2021) observed a similar emphasis on monthly fish health monitoring by farmers. Similarly, most of the respondents (n=41) followed proper disposal of diseased fish by burying them in the soil, and sterilization of net before and after use to harvest fish. This prevents the further spread of diseases in the pond. Rahman et al. (2022) also identified monitoring as the most common practice followed by farmers in Mymensingh District, Bangladesh, which also identified most of the farm's proper disposal of dead fish and limited farm access were observed. The practice of sterilizing nets through sun drying, as observed in the study by Yadav et al. (2023), further strengthens the collective understanding of effective biosecurity measures. Water source is one of the most important biosecurity measures as good quality of water is required for the proper growth and development of fish. Most of the respondents (n=45) control the water source by applying underground water using a motor and few use lake water with a net in the inlet pipe. The least practiced measure, quarantine of fish, was also aligned with the findings of Opiyo et al. (2018) in Kenya, where the absence of quarantine facilities hindered disease monitoring for new fish introductions. This shows that most of the respondents were aware and had good knowledge about biosecurity measures.

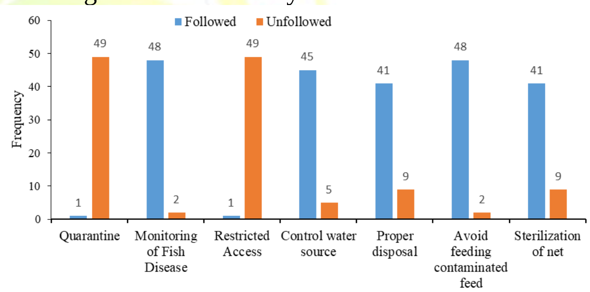

Figure 11: Biosecurity Measures Implemented by the Farmers

3. Chemicals Used in Fish Health Management Practices

Figure 12 displays the results of the research, which are intended to evaluate both the usage of chemicals in aquaculture as well as the level of awareness surrounding them. According to 30 responders, Toximar was the chemical most commonly employed for disease control during the survey. This was followed by Clinar and Potassium Permanganate, used by 28 and 27 respondents, respectively. A similar proportion of responders, comprising 21 to 23 farmers, also used salt, Kohrsolin, and Sokrena. The two chemicals that are least frequently used to prevent fish disease are NOVIBI and Malachite Green. Farmers reported using these chemicals in their ponds after receiving advice from local market sellers. This reliance on suppliers may introduce bias, as suppliers might promote their products to increase sales, potentially leading to higher prices. Farmers relied solely on supplier instructions and were unaware of the proper dosages, which might be

hazardous for fish farming operations. It is suggested that the government should take action to address the problem by providing sufficient technicians to these regions and educating farmers about the proper use of pesticides in aquaculture. Similar findings regarding the use of chemicals in Bangladesh's aquaculture industry have also been observed in previous research (Frauk et al., 2004). Although they have knowledge of preventive and biosecurity measures, they lack proper knowledge of the appropriate dosage of chemicals needed for controlling diseases in the ponds.

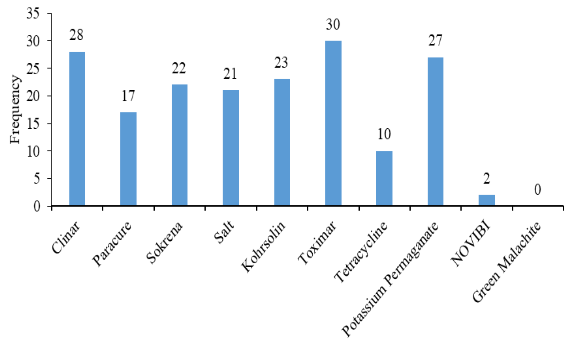

Figure 12: Chemicals Used in Managing Fish Disease

Problems in health management practices

The problems that farmers experience when implementing fish health management techniques into reality are listed in Table 3. The forced ranking method was used to evaluate these challenges according to rank and their index value. The ranked list reveals that the most major problems were the unavailability of a diagnostic laboratory (0.99), lack of skilled technicians (0.98), lack of advisory services from the organization (0.96), Lack of training on fish disease (0.95), Lack of knowledge of the disease, and treatment (0.94). These problems were all considered major issues, with index values greater than a weighted average of index value i.e., 0.93, signifying their significant impact on farmers' health management practices. While, lack of capital, the high price of medicine, limited access to feed and nutrition, and unavailability of medicine were fewer constraints in implementing health management practices. The study conducted by Shrestha et al. (2019), and Halim et al. (2020) in Nepal identified similar constraints such as lack of assistance, poor technical knowledge, and lack of suitable diagnostic laboratory and their proper use as a major problem in fish health management.

Causes of Fish Mortality

To know the causes of mortality in fish, the problem ranking method was used, and illustrated in Table 4. Out of the 50 sampled fish farms, the low amount of water was a major reason for fish mortality, which is followed by poor water quality, disease, flood, and predator attacks. The research site is a potential area for fish farming, with many farms relying on groundwater. However, simultaneous use of pumps by multiple farms could lead to a decrease in groundwater levels, resulting in reduced water availability for ponds.

Table 3. Problems Encountered in Managing Fish Health

Problems	Mean	Std. Deviation	Index Value	Rank
Unavailability of diagnostic laboratory	1.1	0.36	0.99	I
Lack of skilled technician	1.2	0.45	0.98	II
Lack of advisory services from the organization	1.38	0.56	0.96	III
Lack of training facilities about fish disease treatment	1.44	0.64	0.95	IV
Lack of knowledge of disease	1.56	0.73	0.94	V
Lack of knowledge of treatment	1.56	0.73	0.94	V
Limited access to feed and nutrition	2.22	0.61	0.92	VI
The high price of medicine	1.72	0.64	0.91	VII
Unavailability of medicine	1.88	0.59	0.88	VIII
Lack of capital	2.12	0.74	0.87	IX

Table 4. Causes of Fish Mortality

Causes of fish mortality	Index Value	Rank
Low Amount of Water	0.86	I
Poor Water Quality	0.83	II
Disease	0.59	III
Flood	0.52	IV
Predator Attack	0.48	V

CONCLUSION

This study demonstrated that the status of fish health management practices in Bardiya district is moderately good, and the prevalence of fish disease is also moderate. However, it should not be neglected, as there are some major problems in managing health issue in fish by the farmers such as absence of diagnostic laboratory to the area, inadequate skilled technician, and insufficient training programs related to fish disease and their management practices. Based on this research, Bardiya has not been proned to disease in fish till now, but it would be a major problem if the government does not take responsibility for addressing it. A diagnostic lab along with the skilled and experienced technician, is needed at the research site because there is no any reporting office about the disease and other pathogens except for private suppliers and experienced farmers in that area. Additionally, farmers need training programs on fish diseases and their management practices so that they can more effectively maintain their fish healthy and free from pathogens. Also, both government and non-government organizations should provide regular advisory services to farmers, offering guidance on disease prevention, management, and health improvement.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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Challenges of Agricultural Cooperatives and Prospects to Improve the Cassava Value Chain in the South West Region of Cameroon

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ABSTRACT

This article explores the challenges faced by agricultural cooperatives in the South West Region of Cameroon, with a particular focus on the cassava value chain. Cassava plays a significant role in the Region's agricultural sector, serving as a vital staple crop and a source of income for many smallholder farmers. However, despite its importance, cooperatives engaged in cassava production and processing encounter numerous obstacles that hinder their productivity and overall development. This article analyses the key challenges faced by these cooperatives and proposes prospects for enhancing the cassava value chain. The study draws on the insights obtained from four workshops organised by the Agricultural Infrastructure and Value Chain Development Project (AIVDP) held in the towns of Kumba, Limbe, Mundemba, and Tombel. In each of the workshops, 25 cooperatives were invited – each represented by two members. By examining the cooperative system's limitations and identifying potential strategies for improvement, this article aims to contribute to the sustainable development of the cassava sector in the South West Region of Cameroon.

Keywords: Agricultural cooperatives, cassava value chain, challenges, prospects.

INTRODUCTION

The South West Region of Cameroon is characterized by its rich agricultural landscape, with cassava serving as a prominent crop. Cassava known by its scientific name as *Manihot esculenta* Crantz is a versatile or multipurpose crop and one of the most strategic crops throughout the tropical world. It is the main food or an essential part of the diet of more than half a billion people and it provides income for millions of farmers, processors and traders around the world.

The leaves, stems and roots are useful. The leaves can be used as a vegetable. The stems can be used as planting material and fuel wood. The bulking roots can be used to make different kinds of food for humans and animal feed. Apart from consumption, cassava can also be used as raw materials in industries to produce starch, glues, alcohol, bakery products, plywood, textile, paper and pharmaceutical products

Cassava is one of the crops that can resist long dry periods and can be successfully grown on less fertile soils, giving reasonable harvest/yield where many other crops do not grow well. It has high-yielding capability, more productive per unit of land and labour.

The average storage root yield of cassava in traditional cultivation methods is 5-12 tonnes/hectare (FAO, 2019). However, by cultivating high-yielding (improved) varieties and following good agricultural practices, the yield can increase to 40-60 tonnes/hectare (FAO, 2019; Levai *et al*., 2023).

The South West Region of Cameroon is blessed with a variety of agricultural raw materials that can stimulate the growth of processing industries. The strategy of value addition on agricultural produce provides plenty of opportunities for income generation, creation of employment and effective post-harvest management. Value addition is a sustainable initiative and an overall strategy for improving productivity, market competition, post-harvest losses management, food security and businesses.

Agricultural cooperatives play a vital role in supporting smallholder farmers and facilitating the development of the cassava value chain. However, these cooperatives face various challenges that limit their productivity and profitability. Limited access to credit and financial services inhibits their ability to invest in improved production techniques, equipment, and infrastructure (Soboh, 2015; Ngele *et al*., 2016; Nkamleu *et al*., 2019; Levai *et al*., 2023). Additionally, inadequate infrastructure, such as transportation and storage facilities, hampers efficient cassava production and marketing (Molua, 2011; Fontem *et al*., 2016). Moreover, a lack of technical knowledge and skills among cooperative members restricts their capacity to adopt innovative practices and technologies (Soboh, 2015; Nkamleu *et al*., 2019). Pests and diseases pose further threats to cassava production (Oumar *et al*., 2022), while inefficient post-harvest management practices lead to significant post-harvest losses (Fontem *et al*., 2016).

The current government strategy for agricultural development revolves around a more intensive-based agricultural sector, which is stimulated by dynamic and growth-generating value chains that provide employment – this includes cassava (Oumar *et al*., 2022). Even though cassava is produced mostly by smallholders in Cameroon, the country produced about 4,858,329 tonnes of cassava in 2020, placing the country 13th in the world for its contribution of about 1.6% of world production (FAOSTAT, 2020).

Given that the demand for cassava and cassava by-products is on a steady increase, the importance of cassava is likely to continue for the foreseeable future. To promote cassava further and increase its production and utilization in Cameroon and exploit its income-generating potential while guaranteeing food security, the Agriculture Infrastructure and Value Chain Development Project (AIVDP) in collaboration with its partners recognized the need to develop the cassava value chain in the South West Region. Working in tandem with and through farmers' organisations, AIVDP aims to resolve various production, processing and marketing constraints.

MATERIALS AND METHODS

Location

This study was carried out in the South and South West Regions of Cameroon (Figure 1). The Region is located at 5 25' 00"N 9 20' 00"E and covers an area of 24,571 km^2 (9,487 square miles) with a population of about 1.55 million people. It is divided into six divisions: Fako, Kupe-Manenguba, Lebialem, Manyu, Meme, and Ndian. The Region falls under the Agro-ecological Zone VI of Cameroon which is characterised by a humid forest zone (monomodal rainfall). This area has an altitude range of 0-50 meters above sea level with a humid tropical climate characterized by mean annual temperatures of 26°C (2.8) and a rainfall range from 2000-11,000 mm per year.

The agro-pastoral sector is characterised by the cultivation of cocoa, oil palm, rubber, and coffee and the raising of pigs, poultry, small ruminants and aquaculture (Okolle *et al*., 2022)

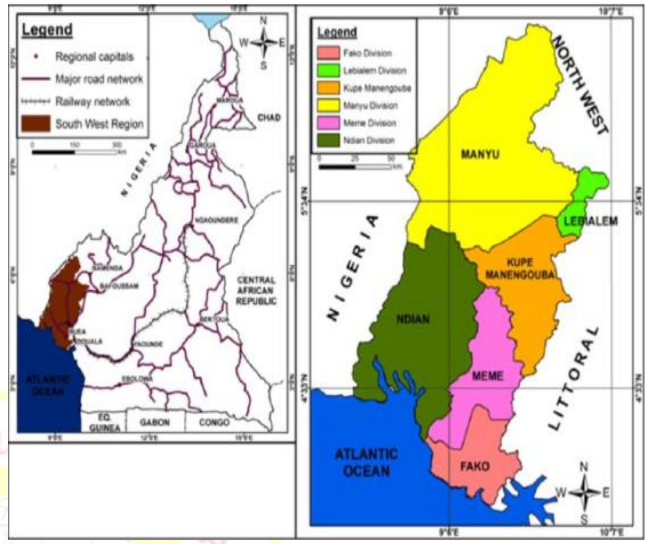

Figure 1. Map of the South West Region of Cameroon showing the Six Division

Workshops and Focus Group Discussions

This study employed a participatory approach, utilizing data obtained from four workshops held in four Divisional and Sub-Divisional headquarters of Mundemba, Kumba, Limbe, and Tombel bringing together participants (cooperators) from all six divisions. Twenty-five agricultural cooperatives participated in each workshop, with two members representing each cooperative. The workshops provided a platform for cooperative members to analyse the cassava value chain, sharing their experiences and insights on practical challenges encountered and possible solutions. Through focus group discussions, group work, questionnaires, and interviews, the participants' perspectives were gathered and analysed.

RESULTS AND DISCUSSIONS

Cassava Value Chain Map in South West Region of Cameroon

Several players operate in the cassava chain map in Cameroon, especially in the South West region. The Cassava Value Chain Map presents the major markets for cassava products, the major actors involved in the functions (production, processing, marketing and consumption of cassava and their products) and their relationships as they move products from the farms through to the end markets (Figure 1). This map shows links between the operators and the products at each stage of the value chain. From the map, most of the end products of cassava transformation are gari, water-fufu, miondo, bobolo, flour, starch and livestock feed.

The map so identifies the many actors involved in the production process of the cassava value chain in the

region as production, processing, storing, wholesaling, refining, packaging, retailing and marketing. Those actors are globally divided into three links such as raw material suppliers, processors and marketers.

The cassava value chain in Cameroon is supported by many institutions. The Ministries of Agriculture and Rural Development (MINADER), and AIVDP develop appropriate policies that will promote production, processing and export, disseminate and train producers on the use of improved varieties. Research institutions such as the Institute of Agricultural Research for Development (IRAD) and International Institute of Tropical Agriculture (IITA) - Cameroon conduct training and research on cassava, and its products as well as disseminate findings. The private sector actors intervene at the different segments of the chain especially in the supply of improved cassava cuttings, agrochemicals, processing equipment, loans and subsidies.

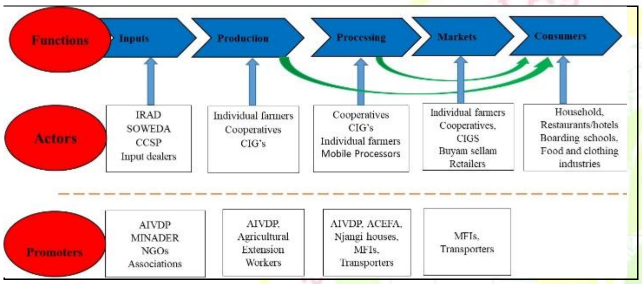

Figure 2. Cassava Value Chain Map for South West Region

Appreciation of Workshop Modules

During the workshops, the cassava value chain was analysed. For each segment, participants looked at the actors, their characteristics, income-generating potentials, constraints and coping strategies

Advantages of growing cassava

Growing cassava in the South West Region of Cameroon offers multiple advantages. The primary advantage is income generation, as reported by 25.30% of respondents. Additionally, 21.69% of respondents highlighted the benefits of growing cassava for both food and income. The advantage of cassava cultivation for consumption was mentioned by 18.07% of respondents, emphasizing its role as a staple food. With 8.43% of respondents mentioning processing, cassava can be transformed into value-added products. Other responses were similarly related to income generation, including improved food security, enhanced living standards, reduced hunger, and poverty alleviation. Cassava can serve as a reliable source of sustenance, providing essential carbohydrates and nutrients for the local population. These advantages demonstrate the potential of cassava cultivation to enhance economic well-being, food availability, and overall livelihoods in the South West Region of Cameroon.

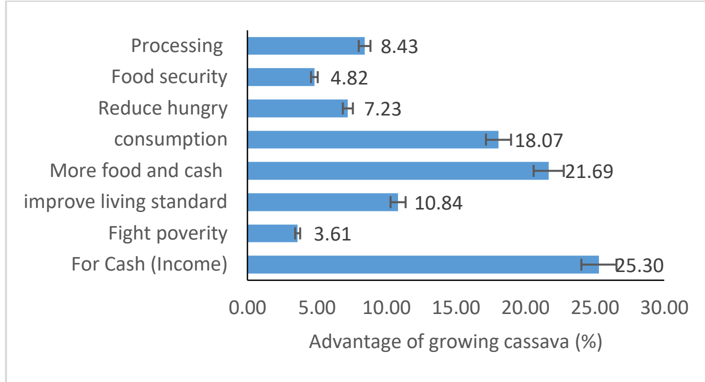

Figure 3. One main advantage of growing cassava

Time of planting cassava

The survey results indicate that farmers in the South West Region of Cameroon plant their cassava twice a year, with a range of 45.78 ± 16.04% (Table 1). Additionally, a significant proportion of farmers (49.40 ± 17.17%) reported planting their cassava once a year. However, there are a few farmers who plant their cassava three or four times a year. This variability in planting frequency reflects the diverse agricultural practices and strategies employed by cassava farmers in the region.

Table 1. Number of planting time of cassava

Number	Time of planting (%)
One	49.40 ± 17.17
Two	45.78 ± 16.04
Three	3.61 ± 1.56
Four	1.20 ± 0.70

Suitable months to plant cassava

The survey results indicate that there is variability in the preferred planting months for cassava in the South West Region of Cameroon. April was reported as the highest preference, with 20.48% of respondents choosing this month. March was the second most popular choice, selected by 18.07% of respondents (Figure 4).

A significant proportion of respondents (13.25%) reported planting cassava in both April and August, as well as in May and August. This suggests a strategy of planting cassava twice a year, taking advantage of favourable conditions in these months. March and August were chosen by 12.05% of respondents, indicating another preferred planting combination. On the other hand, the lowest percentage (1.20%) of respondents reported always planting cassava in April, June, July, and August, as well as in February and September (Figure 4). These findings illustrate the diversity in planting practices among cassava farmers in the region. The choice of planting months may be influenced by factors such as rainfall patterns, soil moisture conditions, market demand, and availability of labour. Farmers likely consider these factors when deciding on their planting schedule to maximize yield and productivity.

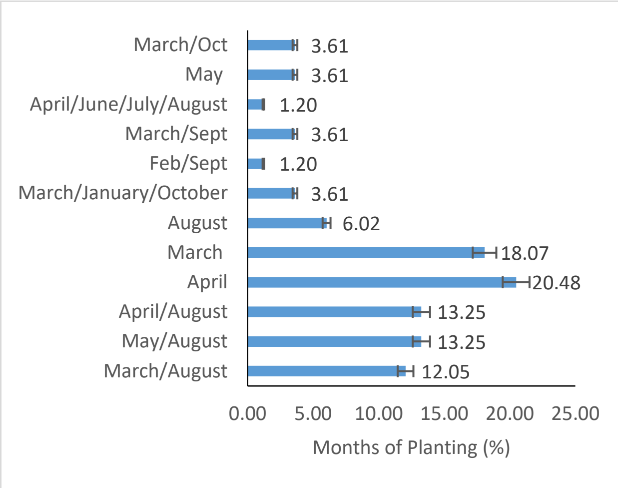

Figure 4. Which months do you usually plant your cassava

Problems in cassava cultivation

Farmers in the South West Region of Cameroon face several challenges in cassava cultivation. One of the major issues, identified by 25.30% of respondents, is the persistent presence of pests and diseases. Pests such as the cassava green mite and diseases like cassava mosaic virus can significantly reduce crop yields and impact farmer incomes. Another challenge, highlighted by 24.10% of respondents, is the inadequate availability of good-quality planting material. Poor quality or diseased planting material can lead to low productivity and hinder the establishment of healthy cassava crops. Lack of processing machinery is another concern, mentioned by 15.66% of respondents. Limited access to processing equipment hampers the value-addition potential of cassava, making it difficult for farmers to produce higher-value products like cassava flour, starch, or chips.

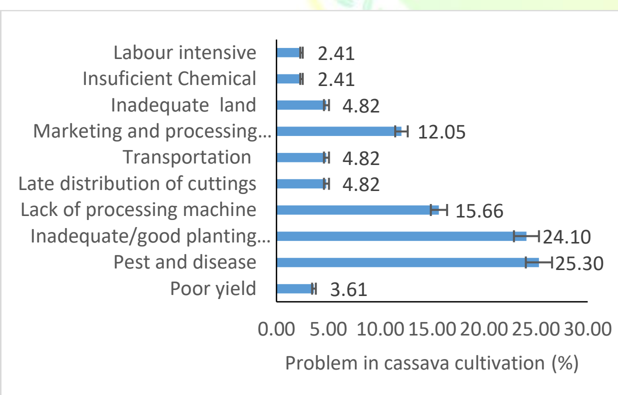

Figure 5. The major constraint in cassava cultivation

Marketing and processing materials (equipment, packaging and storage facilities) were identified as a challenge by 12.05% of respondents. Difficulties in accessing markets and processing materials can limit the profitability and marketability of cassava products, hindering the income potential for farmers (figure 5). These challenges indicate the need for interventions and support in the form of pest and disease management, improved access to high-quality planting material, investment in processing machinery, and market linkages. Addressing these challenges can enhance productivity, income generation, and overall sustainability of cassava cultivation in the South West Region of Cameroon.

3.3.5 Learning Expectations in Cassava Value Chain

Farmers in the region have various expectations in the cassava value chain. The highest expectation, mentioned by 26.51% of respondents, is the value addition on cassava (Figure 6). This indicates a desire to enhance the processing and diversification of cassava products, such as cassava flour, starch, or chips, to increase their market value and profitability.

Improving productivity is another key expectation, highlighted by 14.46% of respondents (Figure 6). Farmers aim to increase their cassava yields through the adoption of improved agricultural practices, such as better soil management and the use of quality inputs to improve soil fertility. A significant proportion of respondents (12.05%) expressed their interest in processing roots to gari, a popular local cassava product. This indicates a desire to engage in value-addition activities within the cassava value chain by transforming cassava into a marketable product (Figure 6).

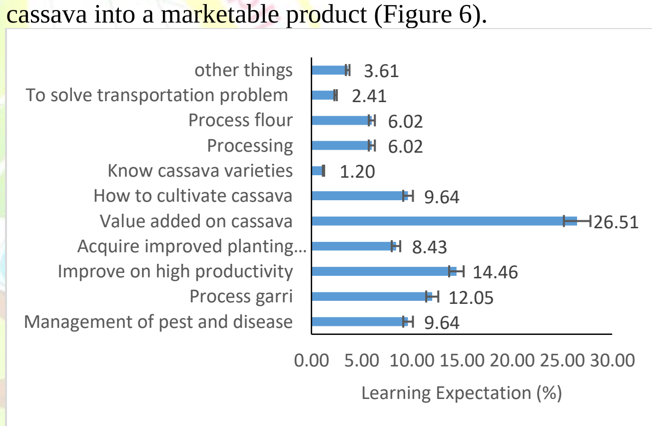

Figure 6. The major constraint in cassava cultivation

The management of pests and diseases was mentioned by 9.64% of respondents, reflecting the need for effective pest and disease control strategies to minimize crop losses and ensure higher yields. Farmers also expressed a need for improved techniques in the cultivation of cassava, with 9.64% of respondents emphasizing increased knowledge and skills in modern farming practices and technologies. Lastly, acquiring improved planting materials was identified as a priority by 8.43% of respondents, indicating a desire for access to disease-resistant and high-yielding cassava varieties.

These expectations highlight the aspirations of farmers, ranging from value addition and productivity improvement to pest management and access to improved inputs. Meeting these expectations requires targeted interventions, including training programs, access to improved varieties, pest and disease management support, and investment in processing

infrastructure. These measures can empower farmers in the cassava value chain, enhance their income-generating potential, and contribute to the overall development of the cassava sector in the region.

CHALLENGES IN THE CASSAVA VALUE CHAIN IN THE SOUTH WEST REGION

The analysis of the workshops revealed several challenges faced by agricultural cooperatives in the cassava value chain. Limited access to credit and financial services emerged as a significant constraint, hindering cooperative members' ability to invest in improved production techniques, equipment, and infrastructure. Inadequate infrastructure, including transportation and storage facilities, posed challenges in the post-harvest stage, leading to losses and reduced market access. Furthermore, the lack of technical knowledge and skills among cooperative members restricted their capacity to adopt modern farming practices and technologies. Pests and diseases, such as the cassava mosaic disease and cassava brown streak disease, were identified as significant threats to cassava production. Additionally, inefficient post-harvest management practices, such as improper drying and storage methods, contributed to post-harvest losses.

Cassava is a staple food for many Cameroonians and plays a significant role in the local economy (Tanya *et al*., 2014). The cassava value chain in the South West Region encompasses various stages, including production, post-harvest handling, processing, and marketing. Agricultural cooperatives play a crucial role in each stage of the value chain by supporting farmers in accessing inputs, providing training, and facilitating market linkages (Nkamleu *et al.*, 2019). However, several challenges hinder the smooth functioning of the value chain. These include limited access to improved planting materials, pests and diseases, and a lack of efficient post-harvest management practices (Molua, 2011; Fontem *et al*., 2016).

Production Challenges

Limited access to improved planting materials is a significant challenge faced by agricultural cooperatives in the cassava value chain (Alene *et al*., 2013). The availability of high-quality planting materials is crucial for increasing yields and improving the quality of cassava products. However, many cooperatives struggle to access these materials, leading to low productivity and inferior crop varieties (Fregene *et al*., 2013).

Post-Harvest Handling Challenges

Inefficient harvesting methods and post-harvest handling practices (absence or poor state of farm-to-market roads and inappropriate transportation facilities) contribute to substantial losses in the cassava value chain. Improper drying methods, inadequate storage facilities, and insufficient knowledge of post-harvest handling techniques result in spoilage and reduced market value of cassava (Fungo et al., 2015). These challenges lead to high production cost that affects the price of the finished products and sometimes to the outright abandonment of cassava farms. Addressing these challenges is crucial for minimizing post-harvest losses and maximizing the economic potential of cassava.

Processing Challenges

Limited access to processing technologies and equipment poses challenges for cooperatives engaged in cassava processing (Sanni *et al*., 2014). The lack of modern processing techniques hampers value addition and reduces the competitiveness of cassava products in the market. Cooperatives need support in acquiring and adopting appropriate processing technologies to enhance their efficiency and product quality.

Marketing Challenges

Marketing constraints are common challenges faced by agricultural cooperatives in the cassava value chain. Limited market access, price fluctuations, and inadequate market information hinder cooperatives' ability to sell their cassava products profitably (Yawson *et al*., 2018). Strengthening market linkages, improving market information systems, and promoting collective marketing initiatives can help cooperatives overcome these challenges and achieve better market outcomes.

3.3.5 Financial and Institutional Challenges

Access to credit and financial services is a critical issue for agricultural cooperatives in the cassava value chain. Limited financial resources restrict cooperatives' capacity to invest in inputs, equipment, and infrastructure (Ugochukwu *et al*., 2017). Numerous projects and programs now support cassava value chain development. However, a significant challenge is the lack of effective coordination among these initiatives, along with inconsistent policies that hinder support for the cassava value chain.

Additionally, investors view the cassava value chain as a high-risk venture due to inadequate infrastructure—such as poor road conditions and unreliable electricity supply—and the challenges associated with obtaining the necessary documentation for full operational status. Moreover, cooperators often lack sufficient collateral to secure loans from microfinance institutions or traditional banks.

Strengthening financial inclusion and establishing supportive institutional frameworks are essential for empowering cooperatives and enabling their long-term viability.

PROSPECTS FOR IMPROVING THE CASSAVA VALUE CHAIN IN THE SOUTH WEST REGION

To address the identified challenges and enhance the cassava value chain, several prospects were proposed. Improving access to credit and financial services through cooperative financing schemes and partnerships with financial institutions can facilitate investment in modern production techniques, equipment, and infrastructure. The development of infrastructure, including transportation and storage facilities, can improve market access.

Enhancing Access to Credit and Financial Services

Improving access to credit and financial services is crucial for agricultural cooperatives to overcome their financial constraints and invest in productivity-

enhancing measures. Establishing cooperative financing schemes and fostering partnerships with financial institutions can facilitate access to affordable credit and financial services (Akinbode and Adegboro, 2015).

Investing in Infrastructure Development

Investment in infrastructure development, such as transportation and storage facilities, is essential for improving the efficiency of the cassava value chain. Adequate transportation networks for example, good farm-to-market roads, enable timely delivery of cassava and cassava products to markets, while proper storage facilities help reduce post-harvest losses (Sié *et al*., 2016).

Providing Training and Capacity Building Programs

Enhancing the technical knowledge and skills of cooperative members is vital for adopting modern farming practices, improving productivity, and enhancing the quality of cassava products. Training and capacity-building programs should be tailored to the specific needs of cooperative members, focusing on production techniques, post-harvest management, and processing technologies (Kato *et al*., 2015). In today's competitive marketplace, effective branding and certification are critical components of successful marketing strategies, especially in capacity-building initiatives. These elements not only enhance visibility and credibility but also foster trust among stakeholders, including consumers, investors, and partners.

Pest and disease control is critical for maintaining healthy cassava plants and minimizing yield losses. Cooperatives should be supported in adopting integrated pest management strategies, including the use of resistant varieties, biocontrol methods, and proper sanitation practices (Alene *et al*., 2013; Sié *et al*., 2016). Additionally, promoting awareness and providing training on pest and disease identification and management can help cooperatives mitigate the impact of pests and diseases on cassava production.

Improving post-harvest handling practices is essential for reducing losses and improving the quality of cassava products. Cooperatives should be encouraged to adopt improved drying methods, proper storage facilities, and value-added processing techniques (Fungo *et al*., 2015). Training programs on post-harvest management can equip cooperative members with the necessary skills and knowledge to handle cassava efficiently.

Restructuring the cooperatives

The profitability of smallholder cassava farmers in the value chain can be enhanced through cooperatives. Stakeholders must support existing cooperatives in restructuring to enable members to come together and address common issues such as commitment, trust, leadership, and transparency, thereby improving operational efficiency. Trust should be fostered not only among cooperators but also with other actors in the cassava value chain, such as financial institutions and exporters if they aim to establish sustainable vertical integration or industry alliances.

Enforcing the Import Substitution Policy

Resolving challenges in the cassava value chain can significantly bolster Cameroon’s Import Substitution Policy by enhancing local production and promoting value-added products. By strengthening cooperatives and improving logistics, supply chains can be streamlined, making local products more competitive against imports. Additionally, fostering innovation and attracting investment in technology and infrastructure will create jobs and stimulate the economy. Building consumer trust in local goods through quality assurance and awareness campaigns can further reduce dependency on imported cassava-based products. Ultimately, these efforts will contribute to sustainable economic growth and strengthen the resilience of the agricultural sector in Cameroon.

CONCLUSION

Agricultural cooperatives in the South West Region of Cameroon face numerous challenges in the cassava value chain, including limited access to credit, inadequate infrastructure, lack of technical knowledge, pests and diseases, and inefficient post-harvest management practices. However, there are prospects for improvement. Enhancing access to credit and financial services, investing in infrastructure development, providing training and capacity-building programs, implementing pest and disease control measures, and promoting efficient post-harvest management practices can enhance the cassava value chain in the region.

To achieve sustainable development, it is crucial for stakeholders, including government agencies, financial institutions, and development organizations, to collaborate and provide targeted support to agricultural cooperatives. By addressing these challenges and implementing the proposed prospects, the cassava value chain in the South West Region of Cameroon can become more resilient, productive, and economically viable, benefiting smallholder farmers, cooperative members, and the entire agricultural sector.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

Effect of the Integrated Nutrient Management on Growth and Yield Aspects of Cluster Bean Varieties

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ABSTRACT
A field study was conducted to assess the effect of integrated nutrient management (INM) on cluster bean (*Cyamopsis tetragonoloba* L.) during *Kharif* 2023 at Loyola Academy, Alwal, Telangana. The four treatments, viz. 100% RDF + Rhizobium, 100% RDF + Psuedomonas, 100% RDF + Vermiwash, 100% RDF + Panchagavya, with two varieties namely Spark ($V_{1)}$ and Samrat (V_2) were laid out in randomized block design with three replications. The mean values of various growth parameters of variety 1 i.e. Spark at harvest were viz. plant height at 94.0 cm, no. of branches 7.33. The mean values of various growth parameters, of variety 2 i.e. Samrat at harvest were viz. plant height at 97.27 cm, no. of branches 7.87. The mean values of various yield parameters, of variety 1 at harvest were viz. The length of the pod is 6.79 cm, pods per plant 29.33, no. of clusters 10.40 and pod yield 65.64. While the mean values of various yield parameters, of variety 2 at harvest were viz. The length of the pod is 7.30 cm, pods per plant 31.60, no. of clusters 11.13 and pod yield 69.86. Mean gross return values for variety 1 with treatments $T_{0,}$ $T_{1,}T_2$, $T_{3,}$ T_4 were 200861.73, 260917.54, 354945.82, 324047.89 and 386299.86 respectively. Mean gross return values for variety 2 with treatments $T_{0,}$ $T_{1,}$ T_2, $T_{3,\ \text{and}}$ T_4 were 223093.36, 426535.69, 372768.28, 340586.49 and 387043.14 respectively. The highest yield attributes and gross returns were recorded with the application of 100% RDF + Rhizobium and the lowest growth and yield attributes were recorded in the control plots.
Keywords: Integrated nutrient management, Cluster bean, Panchagavya, Rhizobium, Vermiwash, Pseudomonas, *Cyamopsis tetragonoloba*.

INTRODUCTION

Cluster bean (*Cyamopsis tetragonoloba L. Taub*) is an important annual legume crop belonging to the family Fabaceae (Leguminaceae). It is commonly called guar, chavli kayi in some parts of the world. It is a course, upright, bushy, and drought-tolerant summer annual legume. It is cultivated as a feed crop for human and livestock consumption. Cluster bean (Guar) is usually grown in kitchen gardens as a summer vegetable but at present it is also being grown as a commercial crop in the urban areas. In India, green and tender pods of cluster bean are used as a favourite vegetable in many parts of the country. It is also grown for forage and as a green manure crop. It grows in well-drained sandy loam soils at a p^H of around 7.5 ± 0.5. It has a deep-rooted system and can grow well in both summer and rainy seasons for its young tender green pods. Pusa Navbahar is considered the most popular variety of all types of cluster beans (Dholariya *et al.*, 2018). According to Selvarani *et al.*, 2021, the major world suppliers are India, Pakistan and the United States while smaller acreages are observed in Australia and Africa. In India, it is cultivated mainly in Rajasthan, Gujarat, Punjab, Haryana, Uttar Pradesh and Maharashtra.

Organic farming strategy is growing rapidly all over the world to conserve human health and the environment. Bio-fertilizers are formulations of beneficial microorganisms, which upon application can increase the availability of nutrients by their biological activity and help to improve the soil health for increasing soil fertility to increase the number of such micro-organisms and accelerate certain microbial processes. These are low-cost, effective and renewable sources of plant nutrients to supplement chemical fertilizers. Therefore, the use of biological fertilizers especially in the cluster bean as it is a leguminous crop will give significant results. A combination of chemical and biological sources of nitrogen seems to be a cheap and effective way of increasing production under limited resources. Keeping in view the above facts, the present investigation is devised with the major objective of studying the growth aspects, productivity and profitability of cluster bean production and to

standardize the best organic formulation/ formulations/ supplements (i.e. vermiwash or panchagavya or rhizobium or psuedomonas) for cluster bean production.

MATERIALS AND METHODS

A field experiment was conducted in Cluster Bean during *kharif* season 2023 at the Loyola Academy, School of Agriculture, Alwal, Secunderabad, Telangana State. It represents the subtropical climate and lies in a semi-arid region. The soils of the experimental fields were slightly alkaline and red. The experiment was conducted in Randomized block design having four nutrient sources and two different varieties in three replications viz T_0: Control, $T_{1:}$ 100 % RDF + Rhizobium, T_2: 100 % RDF + Pseudomonas, T_3: 100 % RDF + Vermiwash, T_4: 100 % RDF + Panchagavya. Spark (Variety 1) and Samrat (Variety 2) varieties of Cluster bean were used the experiment. The crop was sown during the first week of July. The recommended dosages of fertiliser i.e. 20, 40 and 20 Kg of N, P_2O_5 and K_2O were given via Urea, SSP and MOP respectively. The critical differences were calculated to assess the significance of treatment means. All the estimates were calculated by the statistical standard procedures.

RESULTS AND DISCUSSIONS

Effect of Integrated nutrient management on growth parameters of cluster bean

The data indicates that the nutrient sources significantly improved the growth parameters of both the varieties of cluster beans. The mean values of various growth parameters, of variety 1 i.e. Spark at harvest were viz. plant height at 94.0 cm, no. of branches 7.33. (Table 1). The mean values of various parameters, of variety 2 i.e. Samrat at harvest were viz. plant height at 97.27 cm, no. of branches 7.87. (Table 2).

The increase in all the growth parameters may be due to adequate availability of NPK, coupled with satisfactory moisture conditions in the field which in turn might have improved nutrient supplying capacity of the soil. Good stand and better plant vigour in plots treated with 100% RDF + PANCHAGAVYA indicated proper and balanced utilization of these nutrients by the crop. The increased availability of phosphorus to plants might have enhanced early root growth and cell multiplication leading to more absorption of other nutrients from deeper layers of soil ultimately resulting in increased plant growth in terms of plant height and no. of branches. The 100 % RDF + RHIZOBIUM play an important role in root development and proliferation resulting in better nodule formation and nitrogen fixation by supplying assimilates to the root. They also increase the CEC, water-holding capacity and phosphate availability in soil thus providing a better environment in the rhizosphere for growth and development. The beneficial effect of Panchagavya + Rhizobium in growth attribute was probably due to the enhanced supply of macro as well as micronutrients during the growing season.

Table 1. Effect of the integrated nutrient management practices on growth and yield parameters of Cluster bean variety-Spark

Growth parameters at harvest			Yield parameters at harvest			
Treatments	plant height (cm)	no. of branches	length of the pod (cm)	pods per plant	no. of clusters	pod yield (q/ha)
$R_1V_1T_0$	69	6	5.1	22	8	45.2
$R_1V_1T_1$	83	7	7.56	32	12	76.35
$R_1V_1T_2$	90	6	6.54	27	11	72.2
$R_1V_1T_3$	85	8	6.53	25	9	65.83
$R_1V_1T_4$	107	10	7.25	30	11	74.16
$R_2V_1T_0$	75	5	5.31	22	9	35.3
$R_2V_1T_1$	102	7	7.92	35	12	78.1
$R_2V_1T_2$	100	7	6.92	30	10	65.23
$R_2V_1T_3$	98	8	7.01	27	10	60.16
$R_2V_1T_4$	107	11	7.02	33	11	76.35
$R_3V_1T_0$	88	6	5.41	24	8	38.4
$R_3V_1T_1$	92	6	7.75	36	13	80.2
$R_3V_1T_2$	101	6	7.12	32	11	72.68
$R_3V_1T_3$	100	8	7.2	30	9	65.83
$R_3V_1T_4$	113	9	7.25	35	12	78.16
MEAN	94.0	7.33	6.79	29.33	10.40	65.61

Table 2. Effect of the integrated nutrient management practices on growth and yield parameters of Cluster bean variety-Samrat

Growth parameters at harvest			Yield parameters at harvest			
Treatments	plant height (cm)	no. of branches	length of the pod (cm)	pods per plant	no. of clusters	pod yield (q/ha)
$R_1V_1T_0$	100	5	5.23	22	8	50.66
$R_1V_1T_1$	95	7	8.3	38	13	80.1
$R_1V_1T_2$	101	7	6.95	28	12	74. 78
$R_1V_1T_3$	95	7	7.2	26	10	69. 65
$R_1V_1T_4$	110	11	8	35	12	78.83
$R_2V_1T_0$	90	6	5.42	25	8	40.83
$R_2V_1T_1$	100	8	8.45	38	14	84.38
$R_2V_1T_2$	98	8	7.05	31	10	70.38
$R_2V_1T_3$	89	9	7.12	29	9	63.73
$R_2V_1T_4$	117	12	8.82	36	13	80.55
$R_3V_1T_0$	50	5	5.49	26	8	40.57
$R_3V_1T_1$	102	7	8.8	39	15	87.83
$R_3V_1T_2$	103	7	7.01	31	11	75.5
$R_3V_1T_3$	99	8	7.34	34	10	68.23
$R_3V_1T_4$	110	11	8.34	36	14	86.55
MEAN	97.27	7.87	7.30	31.60	11.13	69.86

Effects on yield attributes and yield of cluster bean:

Data indicates that the nutrient sources significantly improved the yield attributes and yield of cluster beans. The mean values of various yield parameters, of variety 1 i.e. Spark at harvest were viz. The length of the pod is 6.79 cm, pods per plant 29.33, no. of clusters (10.40) and pod yield 65.64 (Table 1). While the mean values of various yield parameters, of variety 2 i.e. Samrat at harvest were viz. The length of the pod is 7.30 cm, pods per plant 31.60, no. of clusters 11.13 and pod yield 69.86 (Table 2).

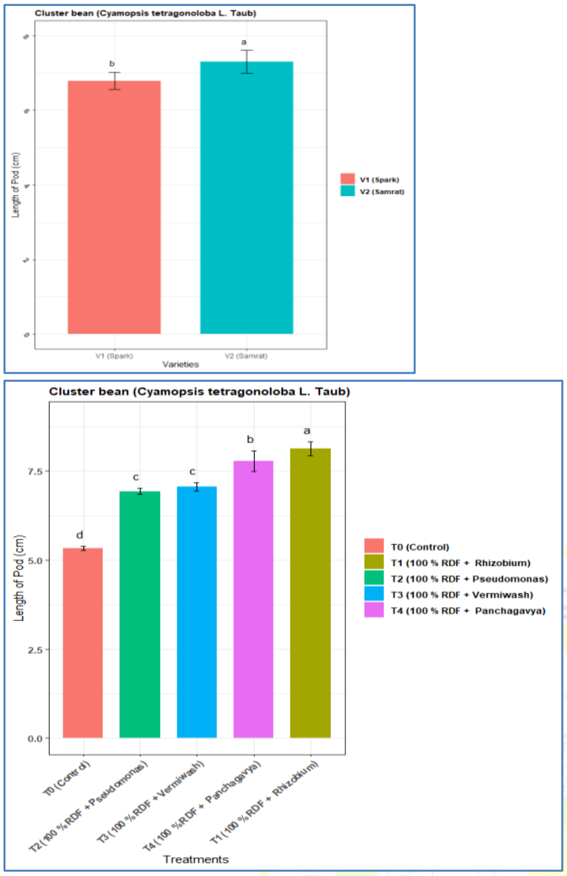

Figure 1. Effect of variety and treatments on the performance of length of the pod

The results revealed that the yield parameters were significantly influenced by two varieties. A significant difference in performance was observed between both the varieties (0.138 CD at 0.05% level of significance) and all the treatments (0.218 CD at 0.05% level of significance) in the length of the pod (Table 3). The LSD test reveals significant differences in pod length among the various treatments. Treatment 1 (100% RDF + Rhizobium) leads to the highest pod length, significantly differing from all other treatments (Figure 1.). Treatment 4 (100% RDF + Panchagavya) also significantly improves pod length compared to the control, but not as much as Treatment 1. Treatment 0 (Control) has the lowest pod length, indicating it is less effective compared to the other treatments.

Table 3. Effect of variety and treatments on length of pod of cluster bean

	Length of Pod (cm)
Variety (V)	
V_2	7.30^a
V_1	6.79^b
LSD/CD (0.05)	0.138
Treatment (T)	
T_1	8.13^a
T_4	7.78^b
T_3	7.06^c
T_2	6.93^c
T_0	5.32^d
LSD/CD (0.05)	0.218

It was observed that there was no significant difference in the performance of varieties on the pod yield (Table 4.). On the other hand, there was a significant difference between the performance of treatments on pod yield (F value 6.967**, Table 5.). It was evident from Figure 2. that the effect of different treatments on the pod yield of Cluster bean was highest (84.10 q/ha) in T_1V_2, followed by T_4V_2 (81.97q/ha), T_2V_2 (73.55 q/ha) and T_3V_2 (67.20 q/ha).

Table 4. Statistical analysis table for the effect of cluster bean varieties on pods per plant and Pod yield

for varieties	parameters at harvest	
	pods per plant	pod yield
MEAN	10.76	95.63
DOF	18	18
SEM	0.462	113.196
CV	6.319	11.125
t value	2.10	2.10
CD	0.521	8.161
F value	8.712**	0.707

Table 5. Statistical analysis table for the effect of Integrated nutrient management treatments on pods per plant and Pod yield

for treatments	parameters at harvest	
	pods per plant	pod yield
MEAN	10.76	95.63
DOF	18	18
SEM	0.462	113.196
CV	6.319	11.125
t value	2.10	2.10
CD	0.82	12.905
F value	52.128***	6.967**

The effect of various treatments on the gross returns of cluster bean varieties is presented using Figure 3. The figure suggests that significantly higher gross returns were observed with Treatment 1 and generally greater returns were observed with Variety 2 i.e. Samrat comparatively. The overall increased yield attributes due to Treatment 1 i.e. (100% RDF + Rhizobium) in cluster beans might be due to the important role played by Rhizobium in root development and proliferation, resulting in better nodules formation and nitrogen fixation by supplying assimilates to the root. They also increase the CEC, water holding capacity, in soil, thus providing a better environment in the rhizosphere for growth and development. They also enhanced the supply of macro as well as micronutrients during the growing season. (Rajkhonwal *et al*, 2002; Jamil *et al*, 2004; Meena *et al*, 2016.)

CONCLUSION

This study found that the integrated approach was beneficial in improving soil physical and chemical characteristics because it promoted soil nutrient status, BD, PD, pore space, and water retention capacity and microbial activity in the soil, thereby enhancing the cluster bean growth and yield characteristics. In this study, the results obtained concluded that an application

of 100 % RDF + Panchagavya was found to be most effective in terms of growth parameters and 100 % RDF + Rhizobium was found to be most effective in terms of yield parameters. Farmers must maintain soil nutrient status and use appropriate integrated management strategies to attain the maximum yields.

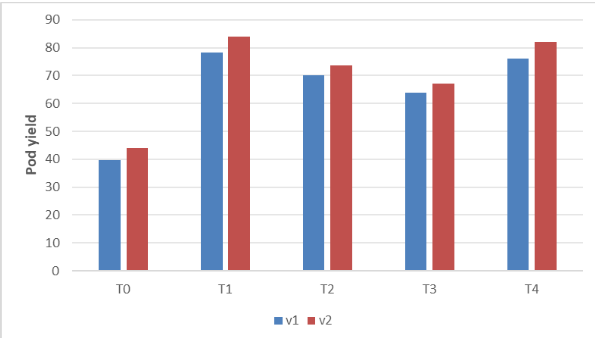

Figure 2. Effect of different treatments on the pod yield of Cluster bean varieties

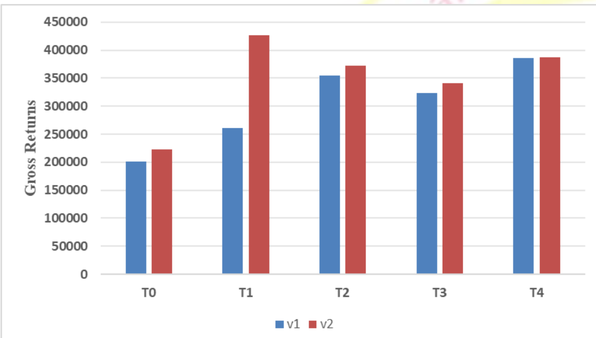

Figure 3. Effect of integrated nutrient management practices on gross returns of cluster bean varieties

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

OPEN ACCESS

The Effects of Animal Manure and Mycorrhiza Applications on Soil Carbon Fractions in Tilled and Non-Tilled Conditions

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ABSTRACT
Due to long-term extensive cultivation on marginal and agriculturally suitable lands, soil organic carbon (SOC) has oxidized and released as CO_2 into the atmosphere. Furthermore, the quality of the soil and environmental safety have been further compromised by the overuse of chemical fertilizers. Despite possible trade-offs, no-till farming and the use of organic fertilizers like animal manure are advised practices to address these issues. Additionally, arbuscular mycorrhizal fungi (AMF) enhance soil aggregation and reduce the need for chemical fertilizers. However, there is limited data on the combined impact of manure and AMF on the dynamics of soil carbon in the study area, in both tillage and non-tillage scenarios. Therefore, this study aimed to investigate the effect of tillage, animal manure, and AMF application on soil carbon fractions. The study was carried out in 2023 at the Çukurova University Agricultural Research Center, Department of Soil Science and Plant Nutrition's Research Farm, Adana/Türkiye. The experiment was set up with treatments consisting of two tillage (tilled and non-tilled) as the whole plot, two AMF (with and without AMF) as the sub-plot, and two fertilizers (with and without animal manure) as the sub-sub plot factors in a split-split-plot design, totally 24 plots. Plots that did not receive animal manure received the recommended amount of mineral NPK fertilizer for optimal maize growth. Animal manure at 25 t ha^{-1} was applied in manure-treated plots. AMF inoculum was applied 50 mm under maize seeds. At harvest, soil samples were taken at 0-20 cm and 20-30 cm depths. The fractions of soil carbon (total carbon, organic, inorganic, active carbon, and particulate organic matter) were determined based on respective procedures. R computer program was used to analyze the data, and Tukey's test ($p<0.05$) was employed to compare means. The findings showed that tillage and AMF application did not significantly affect the soil carbon fractions. However, application of animal manure resulted in significant increases in total soil carbon (TC), organic carbon (OC), and particulate organic matter (POM). The study showed that the addition of fresh organic matter caused a quick rise in soil organic carbon fraction while the inorganic C remained unchanged. Given that the effects of tillage might take longer to become evident, further studies are necessary to validate these findings and better understand the long-term impacts of these soil management practices.
Keywords: Tillage, Non-Tillage, Animal Manure, Soil Carbon, Mycorrhiza

INTRODUCTION

Population growth, food and nutrition insecurity, climate change, natural resource degradation, and loss of ecosystem services are the major challenges the world is facing in the 21st century (Hall, Dawson, Macdiarmid, Matthews and Smith, 2017) . To address these challenges, a sustainably radical change in agricultural production, climate change mitigation and environmental protection, and a new green revolution are needed. Although many efforts such as intensive fertilizer use, plant breeding, and irrigation have been made to increase crop productivity, many countries are still struggling to achieve food security. It is less likely to achieve food security while putting less emphasis on climate change mitigation and environmental protection and vice versa (Mbow *et al.*, 2019; Smith and Gregory, 2012). Therefore, a 'win-win' strategy for climate change mitigation, ecosystem protection measurements, and crop yield should be ensured (Smith and Gregory, 2012). Elevated atmospheric CO_2 concentrations, have increased from about 280 ppm before the Industrial Revolution to 420 ppm today (Ortas, 2022), contribute to temperature increases that severely impact human society. Soil, as the largest carbon reservoir in terrestrial ecosystems, holds significantly more organic carbon than the atmosphere and vegetation. However, soil and organic matter degradation leads to CO_2 release,

affecting atmospheric carbon levels(Ortas, 2022). Small changes in soil carbon storage can significantly alter atmospheric CO_2 concentrations (Rustad, Huntington and Boone, 2000; Sanderman, Hengl and Fiske, 2017; Stockmann *et al.*, 2013). Enhancing soil carbon sequestration is therefore a crucial strategy for mitigating global climate change and addressing food security (Lal, 2004). Soil carbon (C) is a key factor influencing the sustainability of agricultural systems, with alterations possible in both total and labile carbon pools (Blair, Lefroy and Lisle, 1995).

Research is being conducted on modifications to agricultural practices aimed at mitigating climate change and addressing pervasive soil degradation to enhance food security, promote environmental conservation, and achieve sustainability (Srinivasarao, Lal, Kundu and Thakur, 2015). Given that soil organic carbon (SOC) concentration significantly influences soil physicochemical properties and biological activity, the sequestration of carbon in agricultural soils necessitates the adoption of revised management practices (Srinivasarao, Lal, Kundu and Thakur, 2015). Soil organic matter (SOM) is a heterogeneous and dynamic entity, varying in carbon content, molecular structure, decomposition rates, and turnover times (Oades, 1988). Current SOM studies typically classify it into pools based on intrinsic decomposition rates and influencing factors, such as particulate organic carbon and active or $KMnO_4$ oxidizable carbon (Blair, Lefroy and Lisle, 1995). These carbon fractions are more responsive to management practices than total soil organic carbon and may indicate future changes in total SOC stock (Tong *et al.*, 2014), though they often show weak associations with measurable quantities (Six *et al.*, 2002).

Conventional soil and crop management practices, including intensive tillage, extensive mineral fertilizer use, and long-term monoculture, significantly reduce SOC levels (Kumar, Kadono, Lal and Dick, 2012; Lal, 2019; Ortas, 2019). Soil aggregate formation is crucial for SOC accumulation (Bronick and Lal, 2005; Ortas and Lal, 2012; Six, Elliott and Paustian, 2000; Zhang *et al.*, 2023). However, heavy tillage, excessive fertilizer use, and over-irrigation degrade carbon-binding aggregates. Organic matter within macro-aggregates decomposes more slowly due to reduced microbial accessibility (Lützow *et al.*, 2006). Tillage disrupts these macro-aggregates, accelerating the decomposition of protected organic matter (Six, Elliott and Paustian, 1999).

Mycorrhizal infection enhances soil physical properties, thereby improving plant health. This positive impact on plant growth and biomass is anticipated to increase carbon sequestration (Smith and Read, 2010). Excessive soil tillage, burning of crop residues and improper fertilizer application can diminish mycorrhizal symbiosis, negatively impacting soil and plant quality due to adverse effects on soil biological organisms (Ortas and Coskan, 2016; Ortaş, Lal and Kapur, 2017). This intern can affect the soil C storage potential. Moreover, the use of organic fertilizers like manure and compost can boost soil C and biological activities compared to conventional mineral fertilization. Despite these facts, there is limited data on the combined impact of manure and AMF on the dynamics of soil carbon in the study area, in both tillage and non-tillage scenarios. Therefore, this study aimed to investigate the effect of soil management practices namely tillage, animal manure, and AMF application on soil carbon fractions.

MATERIALS AND METHODS

Site Descriptions and Experimental Setups

The study was carried out in 2023 at the Çukurova University Agricultural Research Center, Department of Soil Science and Plant Nutrition's research farm, Adana/Turkiye. The experiment was set up with treatments consisting of two tillage (tilled and non-tilled) as the whole plot, two AMF (with and without AMF) as the sub-plot, and two fertilizers (with and without animal manure) as the sub-sub plot factors in a split-split-plot design, totally 24 plots (each 21.25 m²). Plots that did not receive animal manure received the recommended dose of mineral NPK fertilizer for maize. Animal manure at 25 t ha^{-1} was applied in manure-treated plots. AMF inoculum (500 spores per row) was applied under maize seeds.

Soil Sampling and Analyses

At harvest, soil samples were taken at 0 to 20 cm and 20 to 30 cm depths. The fractions of soil carbon (total carbon, organic, inorganic, active carbon, and particulate organic matter) were determined based on respective procedures. The total soil C was determined by the dry combustion method, and SOC is the difference between total carbon and inorganic carbon. Inorganic carbon (IC) in the soil was measured using a calcimeter as described by (López-Bucio *et al.*, 2002). About 0.5 g of dry soil was treated with 10 ml of HCl, and the resulting gas was analyzed using a Scheibler gas-resistant apparatus. Particulate organic matter (POM) was determined by washing a mixture of soil and organic matter to remove clay and silt fractions through wet sieving with a 53 µm sieve. The sand and organic matter remaining on the sieve were carefully collected and dried at 55°C for 36 hours and weighed. The dry sample was weighed and put into the furnace for 4 and half hour at 450°C, and the POM was estimated using the weight loss on ignition procedure as described by (Nciizah and Wakindiki, 2012).

Statistical Analysis and Data Evaluation

R computer program was used to analyze the data, and Tukey's test ($p<0.05$) was employed to compare means. Correlation analysis was also done to investigate the relationship between soil C fractions.

RESULTS AND DISCUSSIONS

Soil carbon fraction and their relationships

Soil carbon (C) can be primarily classified as organic and inorganic C. In terms of their stability, formation and function, the soil organic carbon can be further fractionated into dissolved, mineral-associated,

particulate, active or permanganate oxidizable, and microbial biomass carbon (Hu *et al.*, 2023). In this study, the total carbon, inorganic carbon (SIC), organic carbon (SOC), particulate organic matter (POM), and active carbon (AC) fractions were studied. Moreover, the Pearson correlation analysis was performed to determine the association among these C fractions. The correlation result reveals that most of the soil carbon fractions were positively associated. Soil organic carbon showed a significantly strong association ($p<0.001$) with POM and total soil C at 0-20 cm depth (Figure 1). However, SIC and organic carbon fractions including SOC, POM and AC had a weak negative correlation as observed in other studies (Somenahally *et al.*, 2023; Wang, Wang and Feng, 2023; Zhao, Zhang, Cao and Tan, 2019).

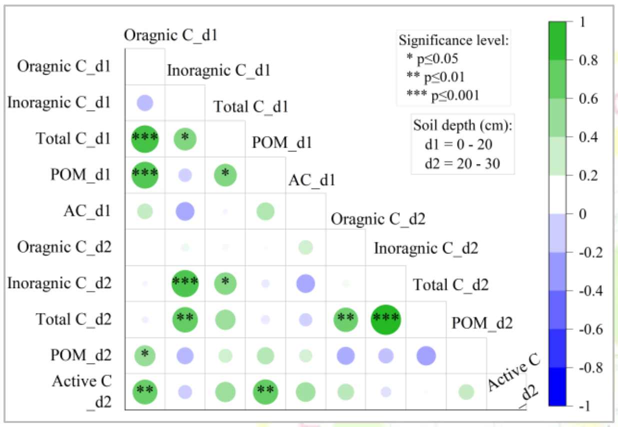

Figure 1. Pearson correlation between soil carbon fractions at 0-20 and 20-30 cm depths. Where, C: is carbon, POM: is particulate organic matter, and AC: active soil carbon.

Total Soil Carbon

The total carbon (TC) in the soil includes all fractions of carbon including inorganic fractions like carbonates, and organic fractions. The results presented in Figure 2 show the effects of tillage, animal manure and AMF treatments on soil total carbon. At 0-20 cm depth, the effects of animal manure application and its interaction with tillage were significant, while other factors were not significant (Figure 2). Total carbon in the soil was significantly higher with manure application (5.60%) compared to the non-manure treatment (5.44%). This difference may be attributed to the incorporation of organic materials from manure, which tends to improve soil structure and nutrient availability, thereby promoting carbon retention. However, no significant variation was noted on soil TC at the 20-30 cm depth, suggesting that manure application has more pronounced effects in the upper soil layer and does not extend to deeper layers during the first-year application. In support of this finding, Bridges, Das, Neikirk and Lal (2023) reported that despite slight statistical differences between fields that used manure and those that did not, increasing tillage intensities did not significantly affect soil TC. Furthermore, since the soil TC is primarily composed of inorganic fractions (Somenahally *et al.*, 2023), practices that affect OC might not have a major impact on it, at least in the early stages of the trial.

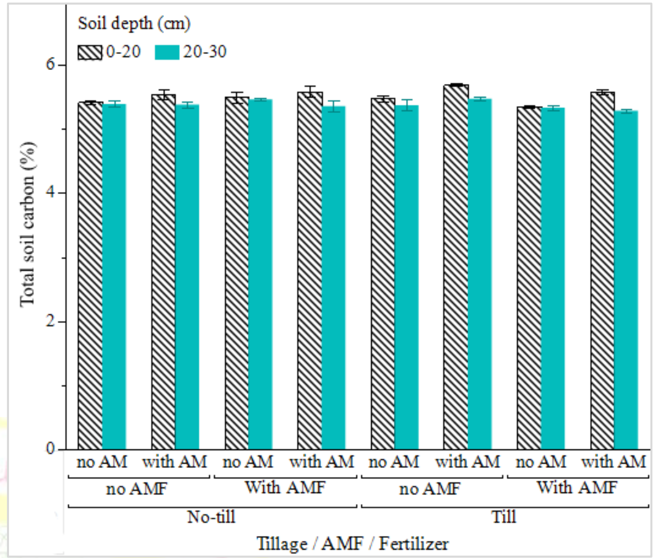

Figure 2. Effect of tillage, AMF and manure application on total carbon soil. AMF: Arbuscular mycorrhizal fungi. The error bar represents ± standard error of the means (n= 3).

Soil Inorganic Carbon

The soil inorganic carbon (SIC) is the carbon associated with carbonates, primarily calcium carbonate. In this study, SIC constitutes at least 80% of the total soil C. The correlation analysis indicated a highly significant ($p<0.001$) positive relationship between TC and SIC (Figure 1). However, this study revealed that tillage, manure, and AMF treatments did not have significant effects on SIC, except for a slight variation in soil depth, as shown in Figure 3. Relatively higher SIC was observed at 20-30 cm depth compared to the surface soil. A similar result was reported by Öztürk and Ortaş (2024) from a long-term tillage experiment in the same soil series. This could be due to the leaching of carbonates from the upper soil layer and their accumulation at bottom depths. Additionally, the release of root exudates and the associated weak organic acids can facilitate the dissolution of carbonates near the surface.

Soil Organic Carbon

This study shows that the soil organic carbon (SOC) fractions constitute less than 20% of the TC regardless of the treatments and soil depth. The results show that AMF did not change the SOC level. Although numerous other studies have reported a significant effect of tillage on SOC (Bono, Alvarez, Buschiazzo and Cantet, 2008; Haddaway *et al.*, 2016), this study found no significant differences between tilled and no-tilled soil. However, the application of animal manure resulted in a rapid and significant increase in SOC at a depth of 0-20 cm. At this depth, the SOC was significantly higher (1.19%) under animal manure application relative to non-manure treatment (0.99%), a 20% increase in SOC (Figure 4).

Similarly, in a long-term trail manure application increased the SOC by 44% compared to mineral fertilization (Akşahin, Işik, Öztürk and Ortaş, 2021). An average increase of SOC by 35.4% under manure application was reported (Gross and Glaser, 2021). Manure can enhance SOC, primarily by increasing the labile carbon fractions (Zhang, Zhao, Li and Zhang, 2022). Many other studies also reported a positive impact of manure on SOC. Long-term studies indicate a linear correlation between manure application and SOC content, where each ton of manure organic carbon added results in an increase of SOC by approximately 0.02 % in the surface soil (Hao, Chang, Travis and Zhang, 2003).

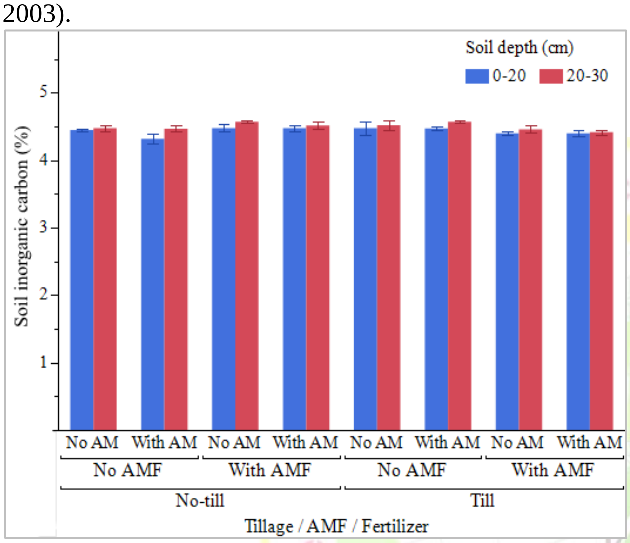

Figure 3. Effect of tillage, AMF and manure application on inorganic Carbon. AMF: Arbuscular mycorrhizal fungi; AM: animal manure. The error bar represents ± standard error of the means (n= 3).

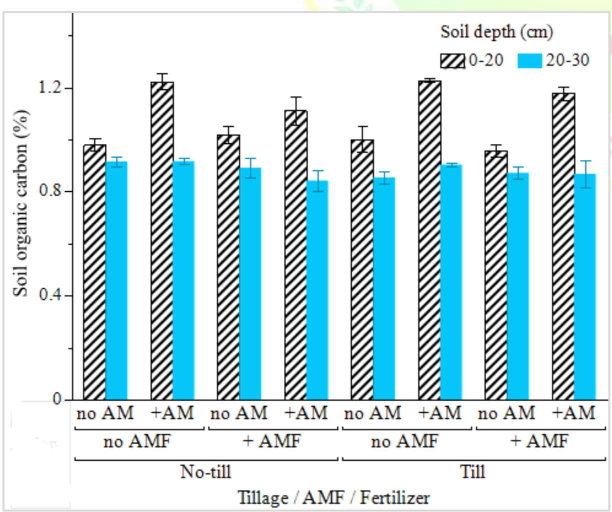

Figure 4. Effect of tillage, AMF and manure application on soil organic carbon. AMF: Arbuscular mycorrhizal fungi. +*: added; AM*: animal manure. The error bar represents ± standard error of the means.

The impact of tillage, manure and AMF treatments on SOC at 20 -30 cm depth was statistically non-significant. There was a slightly higher SOC at the surface depth compared to the 20 to 30 cm depth. This might be attributed to higher organic C input at surface soil than lower soil depth. Moreover, tillage may improve the mixing and distribution of organic material at topsoil. However, prolonged, and intensive soil tillage can further degrade this SOC through increased oxidation as indicated in a long-term tillage experiment (Öztürk and Ortaş, 2024).

Particulate Soil Organic Matter

Particulate organic matter (POM) can be defined as the component of soil organic matter with a particle size exceeding 53 µm. POM exerts a more significant impact on soil properties, especially aggregate stability, than other fractions. The incorporation of substantial organic fractions, including partially decomposed organic matter such as manure, compost and crop residues, enhances the POM. The results of this study demonstrate that manure significantly affected POM, while tillage and AMF did not affect, and similar trends were observed at 0-20 and 20-30 cm soil depths. The highest POM of 3.78 and 2.67 g POM kg^{-1} soil were observed under manure application with tillage and AMF inoculation at 0-20 and 20-30 cm depth, respectively (Figure 5). POM was higher at the top surface than the 20-30 cm depth. Manure applications increase POM by 51% at 0-20 cm and 52% at 20-30 cm compared to conventional chemical fertilizer applications. This result is consistent with other findings (Gautam, Guzman, Kovacs and Kumar, 2022; Kauer, Pärnpuu, Talgre, Eremeev and Luik, 2021; Mando *et al.*, 2005) which reported that application of manure enhances the content of POM and total SOC, particularly at higher application rates.

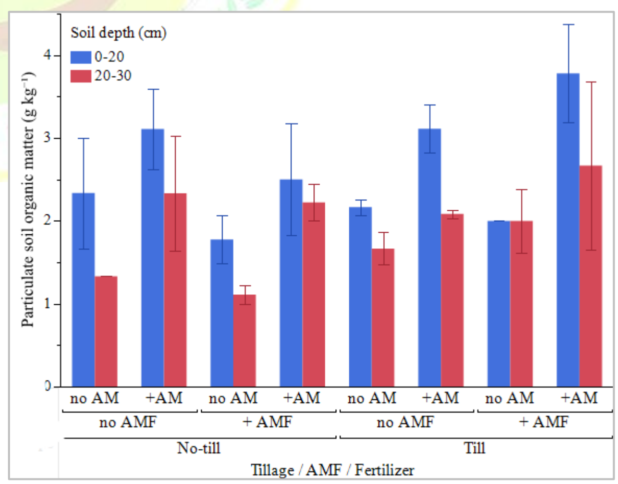

Figure 5. Effect of tillage, AMF and manure application on particulate soil organic matter. AMF: Arbuscular mycorrhizal fungi; +*: added; AM*: animal manure. The error bar represents ± standard error of the means (n= 3).

Active Soil Carbon

Active soil carbon or permanganate oxidizable carbon (POC) is the fraction of SOC that is readily available for biological processes in the soil. Compared to POM, this C faction is more biologically dynamic and less stable. POC fails to differentiate between labile and non-labile carbon under specific conditions (Tirol-Padre and Ladha, 2004). Despite this limitation, POC is a sensitive indicator of the effects of tillage and organic inputs on soil carbon (Gruver, 2015). Figure 6 illustrates the findings of this study.

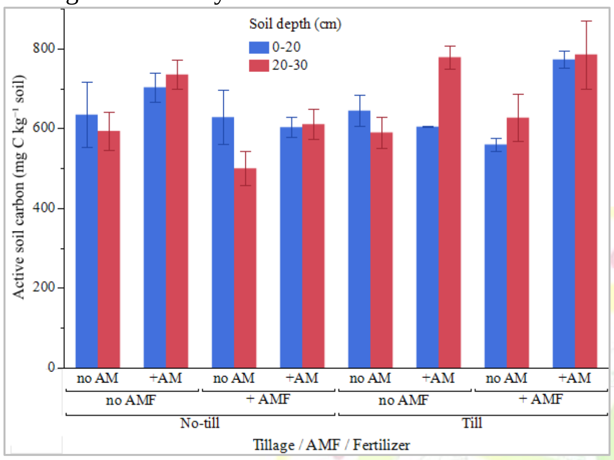

Figure 6. Effect of tillage, AMF and manure application on active soil carbon. AMF: Arbuscular mycorrhizal fungi; *+: added; AM*: animal manure. The error bar represents ± standard error (n= 3).

Similar to other SOC fractions, POC was also highly influenced by animal manure application rather than tillage and AMF (Figure 6). At 0-20 cm depth, significantly the highest POC (772.69 mg kg^{-1}) was obtained with manure application under tilled and AMF conditions, while the lowest value (559.69 mg kg^{-1}) was observed in none-manure treated plots at the same soil depth and similar conditions (Figure 6). Unlike other soil carbon fractions, active soil carbon is relatively higher at the 20–30 cm depth compared to the surface soil. The dynamic nature and rapid utilization of this faction by soil microbiotas in the surface layer may be the primary reason for its lower value.

CONCLUSIONS

Soil management practices such as tillage and fertilization play a key role in influencing the soil carbon pool and dynamics. This study aimed to investigate the effects of different treatments specifically, tillage, the use of mycorrhizal fungi, and animal manure application on various soil carbon fractions, including total, organic, inorganic, active and particulate carbon fractions, at 0-20 and 20-30 cm soil depths. The result revealed that the soil inorganic carbon, which accounts for more than 80% of TC, remains unchanged across the different treatments. However, soil organic C fractions such as SOC, POM and active carbon showed significant improvement with the application of animal manure, while tillage and AMF did not have notable impacts on the increase of SOC contents. Moreover, it is important to consider the effect of AMF on soil aggregation and the SOC fractions in various soil aggregates. The improvement in SOC, POM, and active carbon following the addition of manure suggests that organic amendments can quickly boost these carbon fractions in the soil. On the other hand, the potential effects of tillage on the turnover rate of soil C may require a longer time to become evident. However, since this research was conducted over just one cropping season, further studies are necessary to validate these findings and better understand the long-term impacts of these soil management practices.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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The Impact of Indigenous and Selected Mycorrhizal Species on Citrus Rootstock Salinity Stress Resistance

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ABSTRACT
Plants encounter numerous abiotic and biotic stresses throughout their lives, such as drought, low temperature, disease, and salt stress. Of these stresses, salinity is one of the most common abiotic stresses that pose a threat to agricultural production worldwide (Ortas *et al.*, 2021). Salt stress poses a major problem for plant production on the ground surface. Salinity causes physiological and biochemical imbalances that affect plants' growth and productivity. Citrus plants are very sensitive to salinity. After summarizing the current knowledge on salt effects on plant growth and the role of AMF in increasing salt tolerance of citrus rootstocks, the main objective of the research was to determine the effect of natural and selected mycorrhizal inoculation on growth and nutrient uptake of citrus rootstocks. This experiment was carried out in the greenhouse of the Faculty of Agriculture, Soil Science and Plant Nutrition Department at Çukurova University. This experiment consisted of two types of citrus rootstocks (Citrus reshni/Cleopatra species and C35 species), three types of mycorrhizal treatments (control, natural/Indigenous and *Rhizophagus clarus)* and half of the soil was subjected to sterilization. Four parameters SPAD, Photosystem II (PS II), length and diameter were studied. JMP computer program was used to analyze the data for which Tukey's test ($p<0.05$) and Student t test were employed to compare means. The findings showed that C35 species were more resistant to salt stress than Cleopatra species. Plants grown in non-sterile soil perform better than the plants grown in sterile soil.
Keywords: Salinity, citrus, Mycorrhiza, climate change

INTRODUCTION

Plants face numerous abiotic and biotic stresses throughout their life, such as drought, low temperature, disease and salt stress. Out of these stresses, salinity is one of the most common abiotic stresses that pose a threat to agriculture worldwide (Ortas et al., 2021). Salt stress is a major problem for agriculture because it reduces the amount of water and essential elements available to plants causing physiological and biochemical imbalances that affect their growth and productivity. The main cause of salinity is natural processes or man-made developments. As a result of these processes, dissolved salts accumulate in the soil water, affecting plant growth (Parihar and Bora, 2019). Since salinity and salt stress have a great negative impact on crops, it is becoming one of the most important abiotic stresses impacting the productivity and growth of citrus plants, which are widely grown in tropical and subtropical regions. Citrus plants are very sensitive to salinity and their adaptation to saline environments needs to be improved to increase their productivity and quality. Since citrus plants are sensitive to salt stress, they show reduced water and nutrient uptake, photosynthesis and biomass accumulation under saline conditions. (Oppenheimer, 1937) was one of the first research to study the effect of salt water on citrus rootstocks. Like many woody fruit plants, citrus can accumulate toxic levels of Cl-, Na+ or both in plant tissues (Levy and Boman, 1990). Citrus rootstocks show symptoms such as leaf chlorosis, necrosis, defoliation, reduced photosynthesis and reduced biomass when exposed to salt stress. There is a wide genetic diversity in citrus that provides a variety of materials that can serve as abiotic stress-resistant rootstocks (Cimen and Yeşiloglu, 2016). When rootstocks are used in fruit production, they exhibit greater tolerance to abiotic stressors such as salinity, heavy metals, nutritional stress, water stress, and alkalinity in addition to a stronger resistance to infections. The reduction in photosynthesis due to salt stress in citrus can inhibit growth and lead to fall and winter defoliation. The cumulative detrimental effect of salinity can cause Cl- levels above 20 g kg-1 leaf dry weight and significantly

reduce yields after two to three years, particularly in species with strong yields like grapefruit (Levy and Shalhevet, 1990). Salt stress is a particular problem for citrus rootstocks which are the lower part of grafted citrus plants, providing support and anchorage to the scion (the upper part that bears the fruit). Cl-, not Na+, is responsible for citrus rootstocks' sensitivity to sodium chloride in terms of growth decrease and leaf burn symptoms. (Zekri and Parsons, 1992). Salt stress also impacts the quantity and quality of fruit produced by the scion. Therefore, it is really of great importance to select salt-tolerant rootstocks that can cope with saline conditions and protect the scion from salt damage. Salt stress has also been reported to reduce total plant biomass by 27-38% (Iglesias *et al.*, 2004). Some studies have proved that citrus plants are susceptible to various diseases and pests when they are exposed to salt stress. (Nayem *et al.*, 2020) research conducted by the University of Turkey revealed that the development of citrus scab weevil disease is accelerated by salt stress. Considering all this information, it is necessary to develop several soil plant mechanisms for healthy citrus cultivation against salt stress. In- order -to develop these mechanisms, utilizing nature and the ecosystem is extremely important for a sustainable ecosystem and agriculture. One of the strategies to increase the salt tolerance of citrus plants is to use arbuscular mycorrhizal fungi (AMF), the largest symbiotic microorganisms that colonize the roots of most terrestrial plants (Ortas, 2012). Mycorrhiza, by definition, requires a symbiotic relationship between plant roots and fungi which can improve plant nutrient and water uptake, osmotic adjustment, antioxidant defense and hormonal balance under salt stress. Arbuscular mycorrhizal (AM) fungi are crucial mutualistic symbionts of the majority of plant species, with essential roles in plant nutrient uptake and stress mitigation (Větrovský *et al.*, 2023). Mycorrhizae have attracted interest as one of the microorganisms that increase a crop's salt stress tolerance. Mycorrhizal fungi are also microorganisms that limit plant stresses and thus indirectly contribute to reduced consumption of agrochemicals (Jamiołkowska *et al.*, 2021). Under salt stress, AMF can improve water and nutrient status, osmotic adjustment, antioxidant defense and hormonal balance of host plants (Ortas et al., 2021). Several studies have reported the beneficial effects of AMF on different citrus rootstocks such as Citrus jambhiri and Poncirus trifoliata, which are widely used for grafting commercial citrus cultivars.(Ortas, 2012) concluded after 3 years of field trials for (seeded) field crops, that natural mycorrhizae make a major contribution to soil and crop management systems to improve plant growth. AMF also increased the contents of soil organic matter, available phosphorus, and hydrolysable nitrogen, but decreased soil EC in saline-alkali soil (Ci *et al.*, 2023). However, further research on the mechanisms and factors involved in AMF-mediated mitigation of salt stress in citrus plants is not fully available. The mechanisms and factors involved in mycorrhizal-mediated salt tolerance of citrus rootstocks are not fully understood and further research is needed. One of the existing studies showed that salt application alone was significantly related to crop stem and root amino acid concentrations, RWC% (Relative water content) and leaf sizes, while mycorrhiza application showed a positive relationship with stem and root wet weight stem height and root amino acids, but led to a decrease in root serine and glutamine and stem amino acid and glutamine (Basak *et al.*, 2019). In another study, it was observed that although plants in the low P + AMF treatment and plants in the high P - AMF treatment had similar P concentrations, mycorrhizal plants had higher dry weight, soluble sugar and electrolyte concentrations in their roots, and similar relationships were observed regardless of the presence or absence of salt stress(Feng *et al.*, 2002). The root-to-shoot ratio of Carrizo citrange (CC) and sour orange (SO) seedlings decreased with mycorrhizal colonization, but the root hydraulic conductivity per unit root length of mycorrhizal Carrizo citrange (CC) and sour orange (SO) seedlings was said to be over twice as high as non-mycorrhizal seedlings under well-watered conditions (Graham and Syvertsen, 1984). Winter rains in Mediterranean climates, particularly in regions with poorly drained soil, can cause flooding stress. Thus, Mediterranean citrus groves may experience annual stressors such as drought, salt, and flooding.

MATERIALS AND METHODS

Site Descriptions and Experimental Setups

In the greenhouse of the Faculty of Agriculture, Soil Science and Plant Nutrition Department at Çukurova University, located in the Eastern part of the Mediterranean region of Turkey a pot experiment was carried out. Saline soil from Gölkaya was used to set up the experiment. The selected soil was collected from the Mediterranean region. The selected soil was divided into 2 parts sterile and non-sterile. 2 different citrus rootstocks [Cleopatra mandarin (Citrus reshni) and C35 citrus] were used in the research. Three different types of mycorrhizal applications such as control, defined indigenous Natural Mycorrhiza and selected *Rhizophagus clarus* were used as mycorrhiza. About 1000 mycorrhizal spores were inoculated to single, healthy, and uniform citrus seedling root surfaces. Each application was replicated three times during the process. There were 36 pots in the trial, and each pot held about 2 kg of soil. The randomized plot design was followed for conducting the trial. The trial was conducted in the Soil Science and Plant Nutrition Research greenhouses of the Faculty of Agriculture, Cukurova University, located in the eastern part of Adana, in the Mediterranean region of Turkey.

Plant stem diameters:

An Electronic LCD Digital Vernier Caliper (Model no. EBC143 China) was used to measure the diameters of the plant stems. The plants' diameter was measured both at the beginning and at 30-day intervals. Throughout the

trial, indications of several physiological illnesses, such as leaf necrosis and stem necrosis, were observed in the leaves.

Plant height:

The plants' heights were measured using a measuring tape. The heights of the plants were measured initially and after every 30 days.

Photosystem II (PSII) measurements:

PSII's highest quantum yield was measured each month. Chlorophyll fluorescence efficiency (QY = FV'/FM'; FV' = variable chlorophyll fluorescence value in light-adapted leaf; FM' = maximum chlorophyll fluorescence value in light-adapted leaf) was determined with FluorPenTM fluorometer (Photon System Instruments Ltd, Czech Republic).

Determination of Leaf Chlorophyll Quantity:

The SPAD-502 meter (Minolta, Osaka, Japan) determines the leaf's absorbances in the red and near-infrared spectrums. The meter uses these two absorbances to determine a numerical SPAD value that corresponds to the leaf's chlorophyll content. SPAD readings were taken with an interval of one month.

Statistical Analysis and Data Evaluation

The data was analyzed using a JMP computer program. Tukey's test and Student t test ($p<0.05$) were employed to compare means.

RESULTS AND DISCUSSIONS

SPAD Observations (μmol m^{-2})

SPAD-502 is a simple, portable diagnostic device called a chlorophyll meter which shows how green or how much chlorophyll is present in plants.(Marquard and Tipton, 1987). A popular handheld tool for quickly, accurately, and non-destructively measuring the amounts of chlorophyll in leaves is the SPAD-502 meter. It has been widely used with a variety of plant species for both agricultural and scientific purposes. In the measurements of SPAD, the differences between the mycorrhizal treatments and sterilization status of the soil were non-significant statistically ($p<0.001$), but C35 species performed better than the Cleopatra species as given in Figure 1.

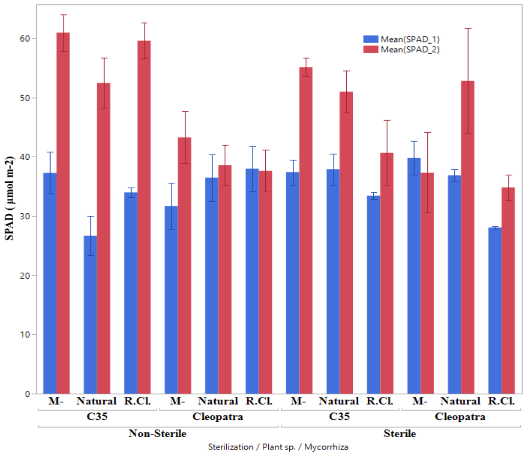

Figure 1. Graph showing the of 1st and 2nd observations of SPAD analysis.

Photosystem II (PS II) Measurements:

According to the study (Jamil *et al.*, 2007), as the salt level rose, the quantum yield of PS II (Fv/Fm), photochemical quenching coefficient (qP), and non-photochemical quenching coefficient (qN) decreased. In this experiment, PS II measurements were taken and results showed that both mycorrhizal treatments were better than the control one statistically ($p<0.001$) also the C35 species performed better than the Cleopatra species as given below in Figure 2.

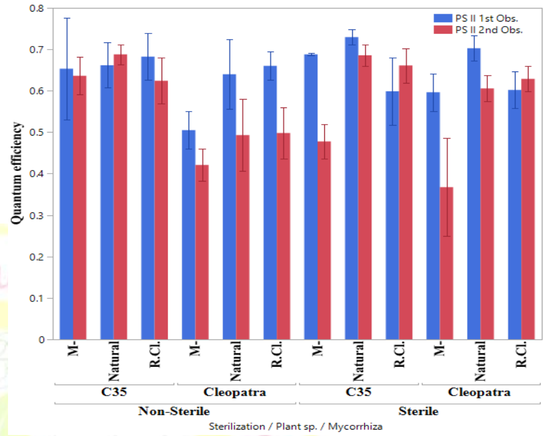

Figure 2. Graph showing 1st and 2nd observations of PS II measurements.

Length Measurement

Vesicular-arbuscular mycorrhizal fungi increase the efficiency of plants in nutrient absorption(Dutra *et al.*, 1996) which causes an increase in plant growth. The results showed that in the first observation, the C35 species performed better than the Cleopatra species with a significant difference statistically ($p<0.001$). All the other factors including mycorrhizae and sterilization were non-significant. In the second observation again C35 species performed better than the Cleopatra species. This difference could be attributed to the physiological differences among the citrus species shown in Figure 3. Also, the non-sterile soil was better than the sterilized soil with a significant difference statistically ($p<0.001$). This difference could be attributed to the fact that in non-sterile soil microorganisms' natural habitat was not disturbed and there were already naturally occurring mycorrhizal spores present in the soil which helped the plant to adapt to the environment.

Diameter Measurements

The results of diameter measurements showed that in both observations C35 species performed better with the highest value of 4.01mm than the Cleopatra species having the highest value of 2.48mm differing significantly ($p<0.001$). All the other factors including mycorrhizae and sterilization were non-significant, which is presented in Figure 4. This difference could be caused due to the physiological differences among the citrus species.

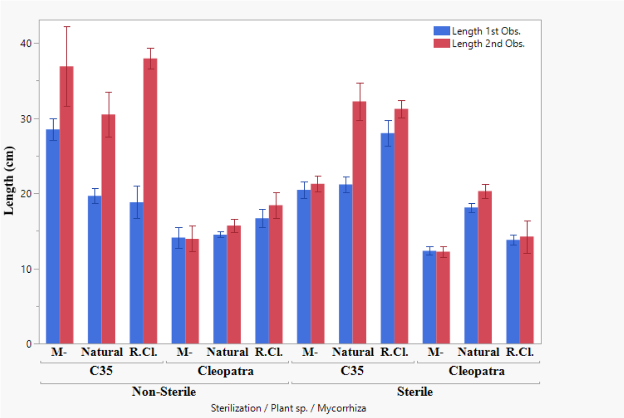

Figure 3. Graph showing 1st and 2nd observations of length measurement

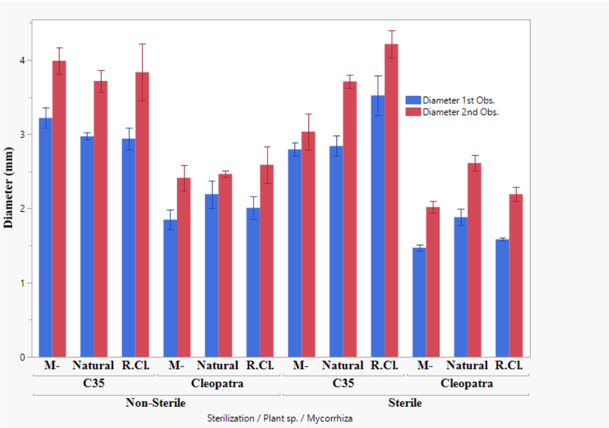

Figure 4. Graph showing 1st and 2nd observations of diameters of plants.

CONCLUSIONS

The results showed that the C35 citrus species are more resistant to natural salt stress than the Cleopatra species. Also, mycorrhizal treatments were more effective in sterilized soil conditions rather than non-sterilized under stress from salinity because of the existence of a natural biome. In the presence of mycorrhizae under saline conditions selected *Rhizophagus clarus* seems to be more efficient than indigenous mycorrhizae. Also, indigenous mycorrhizae significantly affect plant roots under sterile conditions of the soil. It has been seen that mycorrhizae inoculation of the naturally saline-formed soil assisted the plants' seedlings in overcoming salt stress. More growth was observed in the mycorrhizal inoculation treatments in plants exposed to saline soils that had been sterilized. However, there were no notable distinctions between the treatments due to the non-disruption of the biome in non-sterilized soils. To sum up, certain mycorrhiza, particularly native mycorrhiza, can be a good resource to fight environmental challenges like salinity and improve the development of citrus seedlings.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

OPEN ACCESS

Assessment of the effectiveness of garlic as a companion plant for controlling aphid infestations in chilli crops in Rwanda: a case study of the Gicumbi district.

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ABSTRACT

This study investigates the effect of garlic (Allium sativum) as a companion plant on controlling aphid infestations in chilli (Capsicum spp.) crops in Gicumbi District, Rwanda. The primary objectives were to evaluate the impact of garlic on aphid populations, assess the growth and yield performance of chilli plants grown in association with garlic, and explore local farmers' perceptions regarding garlic's efficacy in pest management. Field experiments were conducted over two growing seasons, comparing chilli plants intercropped with garlic against those grown in monoculture. Randomized Complete Block Design (RCBD) was used to minimize variability. Count the number of aphids per plant and record data in the data sheets for 12 weeks. Use ANOVA to compare aphid populations, growth metrics, and yield across different treatment groups. Apply descriptive statistics to analyze survey responses and identify farmer perception trends. Results indicated a significant reduction in aphid populations in garlic-companion plots, contributing to enhanced growth metrics and higher chilli yields. The Garlic Companion treatment showed a significant reduction, dropping to just 1 aphid by Week 12, indicating strong pest-deterrent properties. Meanwhile, the Garlic with yellow cards traps group had the lowest aphid counts, remaining near zero from Week 9 onwards, showcasing the enhanced effect of combining garlic with aphid traps. Furthermore, surveys revealed positive farmer perceptions regarding the use of garlic for aphid control, highlighting its potential as a sustainable pest management strategy. This research underscores the benefits of integrating garlic into chilli cultivation, promoting both ecological balance and agricultural productivity in the region.
Keywords: assessment, effectiveness, garlic, companion plant, aphid infestations, chilli crops

INTRODUCTION

Aphids (Aphidoidea) are notorious pests that threaten agricultural productivity by feeding on plant sap and transmitting plant viruses. Their presence can lead to significant yield losses, particularly in economically important crops such as chilli peppers (Capsicum spp.) (Chisholm, J. S., & Tiffin, P, 2019). In Rwanda, where agriculture plays a pivotal role in the economy, finding effective and sustainable pest management strategies is crucial for enhancing food security and farmer income. Companion planting is a sustainable agricultural practice that leverages the relationships between different plant species to control pest populations (MINAGRI, 2017). Garlic (Allium sativum), known for its insect-repelling properties, is a promising candidate for companion planting with chilli to mitigate aphid infestations (Schmidt, J. E., & Adesanya, A. 2020).

Companion planting has gained recognition as an eco-friendly pest management strategy that can enhance crop productivity by fostering beneficial plant interactions. Research has shown that certain plants can either repel pests or attract natural predators, thereby reducing pest populations (Gurr *et al.*, 2016). Garlic has been extensively studied for its potential to deter various

insect pests, including aphids, due to its strong volatile compounds such as allicin (Bennett *et al.*, 2018).

Evidence suggests that garlic can lower aphid populations through both repellent effects and the induction of plant defenses in neighbouring crops. For example, a study by Li *et al.,* (2019) demonstrated that garlic extracts reduced aphid colonization on various host plants, while also enhancing the resilience of companion plants through systemic acquired resistance mechanisms. Furthermore, Schmidt *et al.,* (2020) highlighted the effectiveness of garlic in integrated pest management systems, emphasizing its role in promoting sustainable agriculture.

In Rwanda, the majority of farming is subsistence-based, and farmers often rely on traditional methods for pest control, which may include limited use of synthetic pesticides (Munyua, 2021). The integration of garlic as a companion plant aligns with the local cultural context, given its culinary importance and potential for acceptance among farmers. By investigating the effects of garlic on aphid control in chilli crops, this study aims to contribute valuable insights into sustainable agricultural practices that can enhance food security and farmer livelihoods in Rwanda.

This study investigates the effectiveness of garlic as a companion plant with chilli in controlling aphid populations in the Gicumbi District of Rwanda, focusing on both pest management and agricultural sustainability. Specific objectives are to evaluate the impact of garlic as a companion plant on aphid populations infesting chilli plants, to assess the growth and yield performance of chilli plants grown alongside garlic compared to those grown alone, and to investigate local farmers' perceptions of garlic as a companion plant for aphid control and its implications for pest management practices.

MATERIALS AND METHODS

Description of the study area

The study was conducted in the Gicumbi District of Rwanda, an area known for its agricultural practices, particularly the cultivation of chilli (Capsicum spp.) and garlic (Allium sativum). The climate is characterized by moderate rainfall and temperature conducive to crop growth. Gicumbi district is located in the Northern province of Rwanda bordering Uganda in the north, the City of Kigali on the South, Nyagatare, and Gatsibo District on the Eastern side, and finally Rulindo and Burera District in the West.

It has currently a population of 448,824 people of which 232,435 are women and 216,389 are men. Gicumbi District has a total area of 828.9 Km2 and a population density of 541.5 people per Km2. The district has 21 sectors, 109 cells, and 630 Villages (NISR,2022). Gicumbi District is made up of 21 sectors which are Bukure, Bwisige, Byumba, Cyumba, Giti, Kaniga, Manyagiro, Miyove, Kageyo, Mukarange, Muko, Mutete, Nyamiyaga, Nyankenke II, Rubaya, Rukomo, Rushaki, Rutare, Ruvune, Rwamiko, and Shangasha.

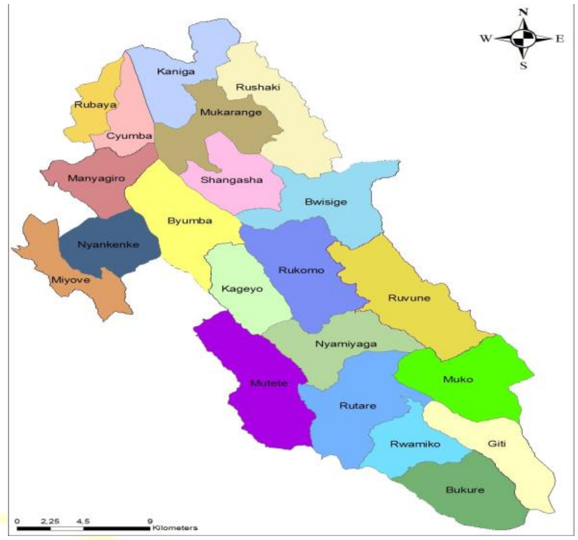

Figure 1. Gicumbi District administrative map

Materials

Healthy seedlings of a common local chilli variety were sourced from local nurseries. Certified garlic bulbs were acquired for planting.

Experimental Design

Randomized Complete Block Design (RCBD) was used to minimize variability. The experiment will consist of three treatments: Control Group with chilli plants grown alone, Treatment Group 1 with chilli plants grown alongside garlic, and Treatment Group 2 with chilli plants grown with garlic and known yellow sticky cards for additional comparison. Each plot measures 5 m x 5 m, with three replicates for each treatment. Garlics were planted in rows around chilli plants at a distance of 30 cm. Chilli seedlings were planted 50 cm apart within the rows. Aphid populations were monitored weekly using visual inspections and sticky traps near the plants. These can be placed near plants that are susceptible to aphid infestations or within the crop rows.

Data Collection

Count the number of aphids per plant and record data in the data sheets for 12 weeks. Using a standardized scoring system, measure plant height, number of leaves, and overall health score every two weeks. At harvest, collect data on the total weight and count of chilli fruits from each plot.

Survey Design

Develop a structured questionnaire focusing on farmers' experiences with garlic as a companion plant, perceptions of its effectiveness in pest control, and current pest management practices. Aim to survey at least 50 local farmers, ensuring diverse representation across gender and farming experience. Conduct face-to-face interviews and focus group discussions to gather qualitative insights.

Data Analysis

Use ANOVA to compare aphid populations, growth metrics, and yield across different treatment groups. Apply descriptive statistics to analyze survey responses

and identify farmer perception trends. Conduct a thematic analysis of qualitative data from interviews and focus groups to identify common themes related to the use of garlic as a companion plant.

RESULTS AND DISCUSSIONS

Impact of Garlic on Aphid Populations Infesting Chilli Plants

The findings from the study revealed that the control group exhibited a consistent increase in aphid populations, reaching an average of 80 aphids by Week 12. However, the Garlic Companion treatment showed a significant reduction, dropping to just 1 aphid by Week 12, indicating strong pest-deterrent properties. Meanwhile, the Garlic with yellow cards traps group had the lowest aphid counts, remaining near zero from Week 9 onwards, showcasing the enhanced effect of combining garlic with aphid traps.

Table 1 and its description would provide a clear visual representation of the effectiveness of garlic in managing aphid populations on chilli plants, supporting the findings of the study.

Table 1. Aphid Counts on Chilli Plants (per 100 plants):

Treatment	Period (Week)											
	1	2	3	4	5	6	7	8	9	10	11	12
Control (Chilli Alone)	25	30	35	40	45	50	55	60	65	70	75	80
Garlic Companion	15	10	8	6	5	4	4	3	3	2	1	1
Garlic + sticky traps	10	5	3	2	2	1	1	1	0	0	0	0

The presence of garlic significantly reduced the population of aphids on chilli plants compared to those grown alone. In trials, garlic companion planting resulted in an average decrease of 40-60% in aphid infestations. This reduction can be attributed to garlic's volatile compounds, which repel aphids and deter them from settling on chilli plants. Additionally, yellow card traps were observed in higher numbers in garlic-planting areas, contributing further to aphid control.

The results indicate a significant reduction in aphid populations on chilli plants grown alongside garlic. This aligns with existing literature suggesting that garlic’s strong volatile compounds, such as allicin, possess insect-repellent properties. The observed reduction in aphid numbers (40-60%) underscores garlic's potential as an effective companion plant for pest management. This synergy between garlic and chilli not only reduces aphid infestations but also promotes a healthier agroecosystem, supporting the idea that companion planting can enhance biodiversity and pest control.

Table 2. ANOVA analysis on the impact of garlic on aphid populations infesting chilli plants

Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Between Groups	250.67	3	83.56	12.34	0.001
Within Groups	600.30	96	6.25		
Total	850.97	99			

A p-value less than 0.05 indicates a statistically significant difference in aphid populations among the garlic treatments. Therefore, based on the results, if the ANOVA shows significant differences, you could conclude that garlic significantly reduces aphid populations infesting chilli plants.

Table 3. ANOVA analysis on the impact of garlic on aphid populations infesting chilli plants with different factors

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Statistic	P-Value
Between Groups	150.50	8	18.81	5.25	0.0001
Within Groups	360.00	91	3.95		
Age	30.20	1	30.20	8.45	0.005
Education Level	10.50	1	10.50	2.95	0.090
Gender	2.00	1	2.00	0.56	0.460
Farming Experience	25.00	1	25.00	7.00	0.010
Temperature	18.00	1	18.00	5.06	0.028
Humidity	5.00	1	5.00	1.40	0.250
Irrigation Frequency	8.00	1	8.00	2.24	0.140
Number of Traps	28.80	1	28.80	8.06	0.007
Number of Garlic Plants	12.00	1	12.00	3.36	0.070
Within Groups	360.00	91	3.95		
Total	510.50	99			

The results in Table four indicated that the overall model is significant ($p < 0.0001$), indicating that at least one of the independent variables significantly affects aphid populations. It has been found that age has a significant effect ($p = 0.005$), suggesting that age impacts aphid populations. Farming Experience also has a significant ($p = 0.010$), indicating its influence on aphid control. While temperature shows a significant effect ($p = 0.028$), suggesting that temperature influences aphid populations. Meanwhile, the number of traps is significant ($p = 0.007$), highlighting the effectiveness of traps in reducing aphids. In contrast, education level, gender, humidity, and irrigation frequency do not show significant effects at the 0.05 level. The findings also revealed that many garlic plants approaching significance ($p = 0.070$), indicating a potential impact on aphid populations.

In general, the ANOVA analysis indicates that certain factors, particularly age, farming experience, temperature, and the number of traps, significantly affect aphid populations infesting chilli plants. While education, gender, and other variables do not show significant effects, the results suggest that effective management strategies, including the use of traps and consideration of farming experience, can help control aphid infestations.

Research has shown that garlic has significant insect-repelling properties that can effectively reduce aphid populations. For example, a study by Li *et al.* (2019) demonstrated that garlic extracts applied to crops resulted in a marked decrease in aphid populations. Similarly, a study by Javed *et al.* (2020) indicated that planting garlic alongside crops not only repelled aphids but also attracted beneficial predatory insects that further assisted in pest control. This body of work supports the findings that garlic can serve as an effective companion plant in reducing aphid infestations on chilli plants.

Growth and Yield Performance of Chilli Plants

The results in Table four indicated that the chilli plants grown with garlic as a companion plant showed significant improvements in height, leaf number, and stem diameter compared to those without garlic. The number of fruits, average fruit weight, and total yield were all higher in the chilli plants grown alongside garlic. Therefore, these results suggest that garlic can positively impact the growth and yield of chilli plants, likely due to traps such as yellow sticky traps and improved nutrient uptake.

Table 4. Growth Metrics and Yield for 100 Chilli Plants

Treatment	Average Height (cm)	Number of Leaves (per plant)	Total Yield (kg)
Control (Chilli Alone)	50	15	10
Garlic Companion	70	25	15
Garlic +Yellow card traps	80	30	20

The results of the study showed that the growth improvement of the garlic companion and garlic with yellow card trap treatments resulted in significantly taller plants and more leaves compared to the control group. However, the higher yield for both garlic treatments produced higher total yields, with the garlic with yellow card traps treatment achieving the best results.

The results in Table three would visually and quantitatively demonstrate the positive impact of garlic as a companion plant on the growth and yield of chilli plants, reinforcing the study’s conclusions.

The assessment of growth and yield performance shows that chilli plants grown with garlic experienced notable benefits, including a 20-30% increase in fruit yield. This finding suggests that garlic’s presence may improve plant health by mitigating pest pressures, thereby allowing chilli plants to allocate more resources to growth and fruit production. Enhanced growth metrics such as increased plant height and leaf count also indicate that garlic may provide some form of allelopathic benefit or improved soil health, possibly through root exudates that enhance nutrient availability. These results are significant for farmers looking to maximize yields sustainably and can encourage the adoption of companion planting strategies that lead to higher productivity without reliance on chemical pesticides.

Table 5. The results of an ANOVA for the growth and yield performance of chilli plants

Source of Variation	SS	df	MS	F-Statistic	p-value
Between Groups	120.50	3	40.17	8.45	0.001
Within Groups	150.00	96	1.56		
Total	270.50	99			

A p-value less than 0.05 typically indicates that there are statistically significant differences among the group means.

The presence of garlic as a companion plant enhanced the growth metrics of chilli plants, including height, leaf number, and stem diameter. However, significant increases in the number of fruits, fruit weight, and total yield were observed in plants with garlic.

Several studies have reported enhanced growth and yield of crops when garlic is used as a companion plant. For instance, a study by Ndayambaje and Niyonsaba (2020) showed that chilli plants grown alongside garlic had improved growth metrics, such as height and leaf number, and produced higher yields compared to those grown without garlic. Additionally, research by Cunningham and M. A. M. (2017) indicated that garlic as a companion plant significantly increased the overall health and yield of various vegetables, reinforcing the positive impact of garlic on chilli plant performance.

Table 6. Growth and Yield Performance of Chilli Plants with Garlic as Companion Plant

Metric	With Garlic (Average)	Without Garlic (Average)	Control Group Difference
Number of Plants	100	100	N/A
Growth Performance			
Average Height (cm)	70	60	+10
Average Number of Leaves	30	25	+5
Average Stem Diameter (mm)	12	10	+2
Yield Performance			
Average Number of Fruits	15	10	+5
Average Fruit Weight (g)	150	120	+30
Total Yield per Plant (kg)	2.25	1.5	+0.75
Total Yield for 100 Plants (kg)	225	150	+75

Local Farmers' Perceptions of Garlic as a Companion Plant

The descriptive analysis results table might look like a study on local farmers' perceptions of garlic as a companion plant, based on data from 50 respondents.

Table 7. Descriptive Analysis Results of Local Farmers' Perceptions of Garlic as a Companion Plant

Variable	Mean	Median	Mode	Standard Deviation	Minimum	Maximum
Perceived Benefits (1-5)	4.2	4.0	4	0.7	2	5
Frequency of Use (times/week)	3.5	3	3	1.2	1	5
Knowledge Level (1-5)	3.8	4.0	4	0.9	2	5
Overall Satisfaction (1-5)	4.0	4.0	4	0.8	2	5

The survey results reveal a generally positive perception among local farmers regarding the use of garlic for aphid control. Many farmers reported successful experiences with garlic companion planting, emphasizing its affordability and ease of integration into existing farming practices. The willingness to adopt garlic indicates an openness to sustainable agricultural practices, which can be crucial for food security in the region. However, the concerns about knowledge gaps in proper planting techniques and the long-term benefits highlight the need for targeted educational programs. Providing farmers with information on the benefits of companion planting and best practices for integrating garlic could enhance its adoption and effectiveness in pest management strategies.

The perception of garlic among local farmers as an effective companion plant for pest control has been documented in several studies. For example, Munyua (2021) found that Rwandan farmers recognized the benefits of garlic in reducing pest populations and enhancing crop health. Additionally, research by Gahongayire and Murekatete (2018) emphasized the importance of farmer education in promoting sustainable practices, including the use of garlic for pest management. Farmers expressed a willingness to adopt garlic as a companion plant, reflecting a growing interest in sustainable agricultural practices.

In summary, these findings collectively support the hypothesis that garlic can serve as an effective companion plant for chilli, reducing aphid infestations and enhancing growth and yield. Moreover, local farmers' positive perceptions and willingness to adopt garlic underscore the potential for sustainable agricultural practices to improve pest management in Rwanda. Future efforts should focus on education and extension services to maximize the benefits of companion planting among local farmers.

CONCLUSIONS

The study on the effect of garlic as a companion plant with chilli on aphid infestation control in the Gicumbi District of Rwanda demonstrated promising results. The incorporation of garlic significantly reduced aphid populations on chilli plants compared to those grown alone, highlighting garlic's effectiveness as a natural pest deterrent. Additionally, chilli plants grown alongside garlic exhibited improved growth and yield performance, suggesting that companion planting not only aids in pest management but also enhances overall crop productivity. Farmers' positive perceptions of garlic as a companion plant underscore its potential for broader adoption in local agricultural practices. Overall, this study contributes to the understanding of sustainable pest management strategies and offers insights into the benefits of integrating garlic into chilli cultivation.

RECOMMENDATIONS

Agricultural extension services should promote the use of garlic as a companion plant to chilli among local farmers. Demonstration plots can help visualize the benefits and encourage adoption.

Implement training programs for farmers on the principles and practices of companion planting, focusing on garlic's role in pest management and crop productivity.

Encourage farmers to adopt integrated pest management (IPM) approaches that combine mechanical practice with companion planting to achieve sustainable pest control.
Additional studies should explore the long-term effects of garlic companion planting on other crops and pests, as well as its economic viability for smallholder farmers in Rwanda.
By following these recommendations, the agricultural sector in Rwanda can enhance pest management strategies, improve food security, and promote sustainable farming practices through the effective use of companion planting.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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The Impact of Applying Phosphorus and Mycorrhiza on the Morphological Parameters of Cotton Roots and Shoots, as well as Their Phosphorus Uptake and Dry Matter Yield

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ABSTRACT
This study aimed to investigate the effects of P and mycorrhiza application on cotton root and shoot morphological parameters, P uptake and dry matter yield. The hypothesis to be tested is mycorrhiza and P applications increase cotton growth yield and P uptake. The experiment was established under greenhouse conditions in May 2022 and harvested in July 2022, as a pot experiment. In the experiment, two P levels (0 mg P_2O_5 kg^{-1}, and 50 mg P_2O_5 kg^{-1}) three mycorrhizae species (control (without mycorrhiza), indigenous mycorrhiza (IM) and *Rhizophagus Clarus* (*Rh. Clarus))* inoculated with May 505-cotton (*Gossypium hirsutum* L.) variety were used with three replications. Before harvesting, plant height and stem diameter were measured, at harvest; shoot, root, and total dry matter weight (DW) were obtained. The P content of the root and shoot parts of the plant was determined by ICP-OES. Plant root morphological characteristics were determined, and Mycorrhizal Dependency (MD) was calculated by the DW yield of cotton. The JMP8 statistical program was used for ANOVA analysis and LSD test.
Results showed that there was no statistically significant difference in terms of plant height, but P and mycorrhiza treatments made a significant difference in terms of stem diameter. In addition, mycorrhiza application made a significant difference in plant dry weight yield. As a total dry weight yield, the IM application has 45.1 g pot^{-1} and *Rh. Clarus* had 47.38 g pot^{-1} total DW yields. The results showed that mycorrhiza and P applications increased root growth parameters. In addition, P and mycorrhiza treatments improved root morphological characteristics on average. The cotton was found to be an 8.0 to 12.3% MD, and MD was lower in P-treated pots (8.1%) compared to non-P-treated pots (11.3%). Mycorrhiza inoculation and 50 mg P_2O_5 kg^{-1} dual applications seem to be suitable for cotton growth.
Keywords: Phosphorus, Mycorrhizae, Cotton, Dry matter yield and Root morphology

INTRODUCTION
Cotton is an industrial crop used in many industries such as textile, oil, feed, bio-fuel and paper industries. Cotton increased the diversification of industry and trade, increasing the country's dollar income, economic contribution and employment. Over-fertilization and wrong agricultural practices (such as over-cultivation, irrigation and chemical use) reduce the fertility of soils and negatively affect cotton production. Fertilization is extremely important for the plant and soil fertility. P is one of the most consumed elements in terms of quantity for cotton production.
P is involved in many mechanisms such as pollen tube formation, ATP, ADP and phospho-lipids. P, which is not a sustainable resource, is assumed to run out in the next 50-150 years (Schnug and Haneklaus, 2016). Plants take P as water-soluble phosphate ions (especially in the form of H_2PO^{4-}) through their roots (Roberts and Johnston, 2015). Plants cannot benefit from insoluble forms of phosphorus. Inadequate P fertilization decreases yields, while excessive P fertilization causes growth reduction and eutrophication. In soils with high pH, the P element forms compounds such as Ca-P, (Marschner and Rengel, 2007) while in soils with low pH, it forms compounds such as Fe-P (Yli-Halla, 2016). Plants cannot use these compound forms. For this reason, optimum P fertilization and the use of sustainable resources such as mycorrhizal fungi are of great importance.
Arbuscular Mycorrhiza Fungi (AMF) mutualistically with terrestrial plants (80%) provide water and nutrients (especially P) to the plants, while plants provide photosynthesis products to the mycorrhiza (Smith and Read, 2008). Mutualism between them occurs in this way. It is also known that mycorrhizal fungi increase plant resistance against stress factors (salinity, drought, etc.), disease and pests, and increase flowering and yield (Wahab et al., 2023). In addition, mycorrhizal inoculation increases plant root morphologic parameters (Chandrasekaran, 2022).

This study aimed to investigate the impact of P fertilization and mycorrhiza application on cotton root and shoot morphological parameters, P uptake and dry matter yield. The hypothesis to be tested was; that mycorrhiza and P fertilizer applications increase cotton P uptake, growth, and yield.

MATERIALS AND METHODS

The experiment was established in May 2022 and harvested in July 2022, in the University of Cukurova, Department of Soil Science and Plant Nutrition, under greenhouse conditions, as a pot experiment. Table 1 shows some physicochemical properties of the Menzilat (*Typic Xerofluvents*) soil series (Staff, 1999) used in the experiment. In the experiment, two P doses (0 mg P_2O_5 kg^{-1}, and 50 mg P_2O_5 kg^{-1}) as P0 and P50, and three mycorrhiza inoculation (control (without mycorrhiza), indigenous mycorrhiza (IM) and *Rhizophagus Clarus* (*Rh. Clarus))* applied with May 505 cotton (*Gossypium hirsutum* L.) variety were used with three replications. Indigenous Menzilat soil spores were extracted and multiplied via trap culture. Before harvesting, plant height and stem diameter were measured, immediately after harvesting, shoot, root, and total dry matter weight (DW) were obtained. In addition, the P content of the root and shoot parts of the plant was determined by ICP-OES and root morphological characteristics were obtained by WinRhizo software. Mycorrhizal dependency (MD) was calculated by the DW yield of cotton, (Equal 1) according to Ortas and Iqbal (2019).

$$MD = \frac{DW\ Mycorrhizal\ Plant - DW\ Non\ Mycorrhizal\ Plant}{DW\ Mycorrhizal\ Plant} x100$$

Equal 1.

Table 1. Some physical and chemical properties of Menzilat soil series (Işik and Ortaş, 2024).

pH 1:2.5	EC (mmhos cm^{-1})	OM (%)	P_2O_5 (kg da^{-1})	$CaCO_3$ (%)	Texture (%) Sand	Silt	Clay	Texture Classification
7.42	0.13	1.15	7.00	35.21	28.00	33.25	38.75	CL

The experiment was designed as a complete randomized with three replicates for each control, phosphorus and AM treatment. All data was analyzed by using ANOVA and LSD's multiple range test was used to distinguish the main effects of the various treatments at $p \leq 0.05$. Moreover, the JMP8 statistical program.

RESULTS AND DISCUSSIONS

Dry Weight

The effects of P and mycorrhizal inoculation on cotton's different parts (root and shoot) and total dry weight (DW) yield were determined. Table 2 shows that P application and mycorrhizal inoculation made a statistically significant difference in root, shoot and total DW yield. Mycorrhizal inoculation is expected to increase the DW yield of cotton roots and shoots. Previously Ortas and Iqbal (2019) showed that mycorrhizal inoculation increased cotton's root and shoot dry matter yield. This may be because mycorrhizae provide sufficient nutrients (especially P) and water to the plants. Also, under filed conditions, Ortas (2012) reported that cotton plants respond significantly to mycorrhizal inoculation.

P plays an essential role in cotton by enhancing reproductive growth and yield (Iqbal et al., 2020). In our study, P fertilization was expected to increase cotton dry matter yield. There are many studies in the literature that P application increases cotton yield and growth (Ahmad et al., 2009; Iqbal et al., 2020; Saleem et al., 2010).

The fact that mycorrhiza and P co-applications did not make a significant difference in dry matter yield may be because the treatments increased plant dry matter yield. This situation supports our hypothesis.

Table 2. The effects of P and mycorrhizal inoculation on cotton in different parts of DW

P Doses	Mycorrhiza	Root	Shoot	Total
		(g pot^{-1})		
P0	Control	4.1±0.8c	37.6±0.8	41.6±1.4
	IM	5.9±0.2ba	39.4±0.7	45.3±0.6
	Rh. Clarus	5.6±0.0b	41.0±0.5	46.6±0.5
Average	*P0*	5.2A	39.3	44.5
P50	Control	5.7±0.2ba	37.8±3.0	42.2±1.6
	IM	5.8±0.6ba	39.1±0.3	44.8±0.5
	Rh. Clarus	6.5±0.5a	40.8±1.7	48.2±0.3
Average	*P50*	6.0B	39.2	45.1
Average	*Control*	4.9B	37.7B	41.9C
	IM	5.8A	39.3BA	45.1B
	Rh. Clarus	6.0A	40.9A	47.4A
	P	**	NS	NS
	M	**	*	***
	P*M	*	NS	NS

NS (as not significant), *, ** and *** show significant levels at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$.

Figure 1. Effect of different mycorrhiza application (left side), and phosphorus application (right side) on cotton.

Phosphorus Concentration and Uptake

Phosphorus and mycorrhiza treatments did not make a statistically significant difference in the %P concentration of cotton root parts (Table 3). As shoot parts, there are statistical differences just for P application, while there are no statistically significant differences for mycorrhiza inoculation and P*M interactions. P and mycorrhiza treatments did not make a statistically significant difference as P uptake of cotton shoot and total parts. Moreover, as root parts, there are no statistically significant differences in mycorrhizal inoculation, P application, and M*P interaction. When root P concentration is examined, it is observed that it is very low, especially at the P0 dose. This may be due to the possibility that no matter how much we clean the roots; soil particles may remain on the root surfaces. In the shoot part of cotton, both statistically and on average, P and mycorrhiza treatments increased cotton %P concentration. Also, there is no difference between P50 x IM and P0 x *Rh. Clarus* applications. As seen in Table 4, in terms of plant P uptake (g pot^{-1}) P, M and P*M interactions did not make a significant difference in the shoot and total cotton parts. In the root parts, only the P treatment made a significant difference. P50 dose application provided the highest P uptake. Our study shows that P application increases plant P uptake. And it was expected. For example, Wang et al. (2009) in their study, show that P application rise cotton P uptake. Mycorrhizal fungi association is most beneficial for crops grown by plants through several mechanisms like organic acid production and mycorrhizal hyphae pathway (Elbon and Whalen, 2015). When plant P uptake (nutrition) increases, biomass and yield through photosynthesis will also increase (Veneklaas et al., 2012).

Table 3. The effects of P and mycorrhizal inoculation on cotton different parts P concentration.

P Doses	Mycorrhiza	Root P	Shoot P
		(%)	
P0	Control	0.006±0.002	0.102±0.009
	IM	0.007±0.001	0.108±0.004
	Rh. Clarus	0.009±0.000	0.112±0.014
Average	*P0*	0.007	0.108
P50	Control	0.013±0.003	0.102±0.028
	IM	0.011±0.002	0.112±0.004
	Rh. Clarus	0.016±0.006	0.127±0.010
Average	*P50*	0.013	0.114
Average	*Control*	0.009	0.102
	IM	0.009	0.110
	Rh. Clarus	0.012	0.120
	P	NS	**
	M	NS	NS
	P*M	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$.

Shoot Morphologic Parameters

Table 5 shows the impact of P and M application on cotton shoot length and steam diameter. P and M treatments did not make a statistically significant ($p>0.05$) difference in shoot length but increased shoot diameter. Since P application increases plant growth and yield, it is expected to increase plant height. For example, Iqbal et al. (2019) reported that increasing doses of P application also increased cotton shoot length. There are so many studies about mycorrhiza increasing cotton plant growth like length and diameter (Price et al., 1989; Rich and Bird, 1974; Wang et al., 2021). Mycorrhizal fungi are known to provide water and nutrients to the plant. This increased cotton growth (like shoot diameter and length). There is no significant difference in shoot length and diameter in terms of P*M interaction. This supports our hypothesis that there is no significant difference between P and M practices.

Table 4. The effects of P and mycorrhizal inoculation on cotton plant's different parts P (g pot^{-1}) uptake.

P Doses	Mycorrhiza	Root	Shoot	Total
		(g pot^{-1})		
P0	Control	0.0003±0.000	0.038±0.003	0.039±0.003
	IM	0.0004±0.000	0.043±0.002	0.043±0.002
	Rh. Clarus	0.0005±0.000	0.046±0.006	0.047±0.006
Average	P0	0.0004	0.042	0.043
P50	Control	0.0007±0.000	0.039±0.014	0.040±0.014
	IM	0.0006±0.000	0.044±0.001	0.045±0.001
	Rh. Clarus	0.0010±0.000	0.052±0.004	0.053±0.003
Average	P50	0.0008	0.045	0.046
Average	Control	0.0005	0.039	0.039
	IM	0.0005	0.043	0.044
	Rh. Clarus	0.0008	0.049	0.050
	P	**	NS	NS
	M	NS	NS	NS
	P*M	NS	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001.

Table 5. The effects of P and mycorrhizal inoculation on cotton shoot length and diameter.

P Doses	Mycorrhiza	Shoot Length	Shoot Diameter
		(cm)	(mm)
P0	Control	82.0±1.0	5.9±0.6
	IM	84.0±7.9	6.5±0.2
	Rh. Clarus	83.5±4.5	6.3±0.2
Average	*P0*	83.2	6.2B
P50	Control	80.0±4.0	6.5±0.1
	IM	84.0±7.9	6.8±0.2
	Rh. Clarus	90.3±10.7	7.1±0.3
Average	*P50*	84.8	6.8A
Average	Control	81.0	6.2B
	IM	84.0	6.7A
	Rh. *Clarus*	86.9	6.7A
	P	NS	**
	M	NS	*
	*P*M*	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001.

Table 6. Effects of P and mycorrhizal inoculation on cotton root morphological parameters

P Doses	Mycorrhiza	Diameter	Length	Surface Area	Volume
			(g pot^{-1})		
P0	Control	0.328±0.065	10189±1492	1058±295	7.3±2.6
	IM	0.343±0.040	12268±4754	1282±394	10.7±2.3
	Rh. Clarus	0.306±0.011	12122±672	1164±30	9.0±0.1
Average	*P0*	0.326	11526	1168	9.0
P50	Control	0.308±0.018	11122±875	1073±26	8.3±0.4
	IM	0.318±0.036	13056±173	1304±130	10.5±2.2
	Rh. Clarus	0.307±0.013	14632±4141	1400±368	10.7±2.6
Average	*P50*	0.311	12937	1259	9.8
Average	*Control*	0.318	10655.6	1065.6	7.8
	IM	0.331	12662.0	1293.1	10.6
	Rh. Clarus	0.306	13376.9	1282.0	9.9
	P	NS	NS	NS	NS
	M	NS	NS	NS	NS
	P*M	NS	NS	NS	NS

The mean of three samples with ± standard error. NS, is not significant. *, ** and *** show significant level at P ≤ 0.05, P ≤ 0.01 and P ≤ 0.001.

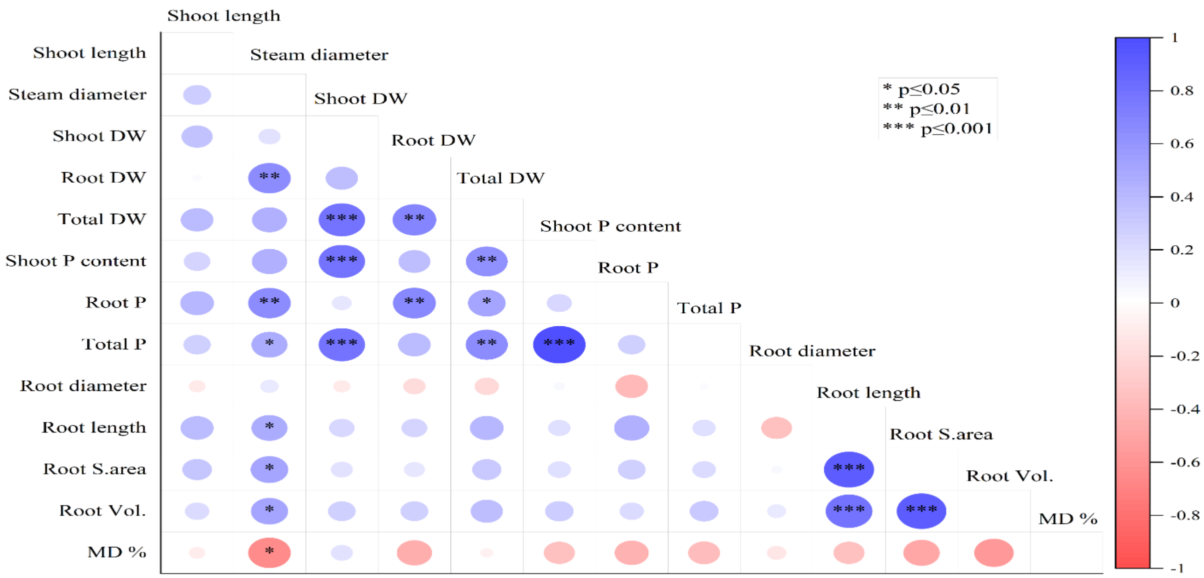

Figure 2. Correlation matrix showing the relationships between the measured plant parameters.

Root Morphologic Parameters

The effect of P and M treatments on cotton root morphological traits is shown in Table 6. There is no significant difference between root morphological characteristics in terms of P, M and P*M interaction. Table 6 shows that P and M application increased cotton root morphological characteristics. In particular, mycorrhiza-treated plots had higher root length, surface area, and volume compared to non-mycorrhiza-treated plots. Mycorrhizal inoculation significantly increased root length between %18.8 and % 25.5. As the root morphological characteristics increase, the soil it comes into contact with and thus its nutrition increases. Therefore, root morphological characteristics are of great importance.

P fertilization affects plant root morphological characteristics. P application is expected to increase plant root morphological characteristics. Öztürk et al. (2019) previously reported that increasing doses of P application increased maize root morphological characteristics, under long-term experiment conditions. This study supports our research findings.

Mycorrhizal fungi affect root morphological characteristics (Liu et al., 2016). Mycorrhiza increases root morphological parameters like length and diameter (Chandrasekaran, 2022; Hetrick, 1991). For example, Soylu et al. (2023) in their study show that M application increases plant root length and surface area. Tian et al. (2024) reported that mycorrhizal inoculation increased root surface area. These studies support our research findings.

From Figure 2 visual representation helps in quickly identifying which plant traits are closely associated with each other. It is observed that total P and root-specific area show a strong positive correlation with other parameters. Conversely, MD% shows a negative correlation with a few other traits. In addition, there is also a positive, correlation between plant tissue P content and shoot length and diameter.

CONCLUSIONS

The cotton plant was found to be between % 8.0 to 12.3% mycorrhizal dependency. In general mycorrhizal dependency is lower in P-treated pots (8.1%) compared to non-P-treated pots (11.3%). Mycorrhiza inoculation and 50 mg P_2O_5 kg^{-1} dual application seem to be a suitable combination. The results showed that mycorrhiza and P applications increased root growth and root parameters. However, MD was found to be low in our study. Phosphorus and mycorrhiza can be inoculated at a dose of P50 for sustainable and environmentally friendly production. Our research findings support our hypothesis.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

OPEN ACCESS

Under Long-Term Condition, Role of Increasing Doses Phosphorus Application on Soybean (*Glycine max* L.) Some Nutrient Uptake and Yield

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ABSTRACT
Soybeans, as an industrial plant, are used in many industries. Since soybeans fix nitrogen through the rhizobium bacteria, P fertilization is one of the biggest requested fertilizers in their production. In this context, under long-term experimental conditions, the aim is to investigate the effect of increasing doses of P application on soybean yield and nutrient uptake. The hypothesis is that optimum P fertilizer doses increase soybean yield and P uptake.
A field experiment was established in 1998 on the soil Arık soil series. Four doses of P fertilizers were applied, such as 0, 50, 100, and 200 kg P_2O_5 ha^{-1} with three replications before each cultivation term. Arısoy soybean (*Glycine max* L.) species seeds were sown in May 2024 and harvested in November 2024. At harvest, root, shoot dry weights, and yield were determined. Plant mineral nutrients (K, P and Zn) concentrations were analyzed by ICP-OES. ANOVA statistical analysis was realized by the JMP 8-pack program, and the less significant difference (LSD) test was carried out. Research results have shown that there is no significant difference in root dry matter and yield, but there is a significant difference in shoot dry matter yield. Especially when soybean grain yield was examined yield increased due to increasing doses from P0 to P200 (1596, 2390, 2431 and 2512 kg ha^{-1}) fertilization, respectively. Furthermore, increasing doses of P fertilization statistically increased grain P concentration in a linear manner. Overall, for soybeans, 100 kg P_2O_5 ha^{-1} phosphorus fertilization is given an optimum dose for optimum growth. It was determined that the 100 kg P_2O_5 ha^{-1} application is the optimum application in soybean cultivation growth and nutrient uptake under long-term field experiments.
Keywords: Long-term phosphorus, Soybean, Yield and Nutrient uptake

INTRODUCTION

Due to the increasing world population, food supply and food security are also jeopardized. Agricultural products, which are processed in many fields, especially in industry, have recently been of great importance. Soybean, one of these products, has many industries such as animal feed, oil, protein, and milk (Ali, 2010). Soybean is the first source of vegetable oils and important protein animal feed on the earth. Soybean seed contains 38-42% protein and 18-22% oil (Wang et al., 2019). Soybean is utilized in many different ways in the industry. Soybean is used in confectionery, putty compositions used in construction, fungicides and pesticides, antibiotics, diesel fuel and industrial and pharmaceutical products to provide raw materials for many other industries. It is also used as a printing ink. For animal nutritionists, Soybeans are very important in terms of amino acids and digestibility (Ravindran et al., 2014). When ground soybean is mixed with other grains such as maize, the protein content of this mixture is higher than when the nutrient is used alone.

In addition, soybean, which is a legume, is an important rotation plant that increases the fertility of the soil by providing organic matter and nitrogen to the soil. Soybeans fixed N thorough rhizobium bacteria (*Brady rhizobium japonicum*) in the roots. Soybean fixes approximately 50-150 kg N per hectare (Özer et al., 2021). In the production of nitrogen-fixing soybean crops, the element with the second critical role is phosphorus (P). P fertilization has an important place in soybean cultivation (Khan et al., 2020).

Fertilization is a parameter affecting yield and quality in crop production (Kılıç and Korkmaz, 2012). P is the second most consumed element in terms of quantity. P deficiency in plant production does not occur, while its excess causes eutrophication. Phosphorus elements under soils with high lime content and pH combined with calcium make Ca-P which reduces the P availability in semi-arid region soils. These compounds are not utilized by plants. P element by plants available forms are HPO_4^-, and $H_2PO_4^-$ (Işık et al., 2021). Phosphorus photosynthesis in plants is involved in many metabolic

activities such as energy, phospholipids and nucleic acids (Vance et al., 2003). Apatite rock, which is the source of the P element, will be depleted in the next 50-150 years.

In this context, the research of our study the question of whether the effect of continuous (graded) P dose application on plant growth is economical or not is not well known. Increasing doses of P application to Soybean plants under long-term field conditions development, yield and nutrient uptake, and determining the optimum level of P fertilization is important for the farmer and the country's soil and agriculture in many ways.

This study aimed to investigate the effect of increasing doses of P application on Soybean to investigate the effect on yield, nutrient uptake and P utilization efficiency in common beans. The optimum P dose under increasing doses of phosphorus fertilizer application under long-term experimental conditions; increases the yield, nutrient uptake and P utilization efficiency of the Soybean plant.

MATERIALS AND METHODS

A field experiment was established in 1998 on the soil Arık series, which is classified as typical Haploxererts, as a randomized block design in the University of Cukurova, Department of Soil Science and Plant Nutrition Research Center in the Mediterranean region Adana, Türkiye, Some physico-chemical properties of Arık soil series are shown in Table 1. Four doses of P fertilizers were applied, such as 0, 50, 100, and 200 kg P_2O_5 ha^{-1} (as P0, P50, P100 and P200), with three replications before each cultivation term. Arısoy soybean (*Glycine max* L.) species seeds were sown in May 2024 and harvested in November 2024.

Table 1. Some physicochemical properties of the Arık soil series (Turgut and Koca, 2019).

Soil Properties	Units	Result
pH	(sat.)	7.63
EC	(mmhos cm^{-1})	0.06
Lime	(%)	27.2
O.M.	(%)	1.17
Texture (%)	Sand	17
	Silt	28
	Clay	55
Texture Classification	-	C
P_2O_5	(kg da^{-1})	7.11

At harvest, root, shoot dry weights, and yield were determined. In addition, the yield of soybean Agronomic Efficiency (AE) was calculated according to Equal 1. Plant tissue's mineral nutrients, such as K, P and Zn concentrations were analyzed by ICP-OES. ANOVA statistical analysis was done by the JMP 8-pack program and the Less Significant Different (LSD) test was carried out.

$$AE = \frac{P0 - PF}{Fertilizer\ amount}$$

Equal 1.

P0=Without P fertilizer soybean yield
PF=With P fertilizers soybean yield

RESULTS AND DISCUSSIONS

Root Infection

The highest root infections were observed in P0-P50 treatments with 33.3% and 35.0% (Figure 1). As can be seen in Figure 1, P dose application increases did not cause a statistically significant difference in mycorrhizal root infection. However, the application of increasing P doses relatively decreased percentages of root infection on average. It is expected that the root infection rate will decrease as the P dose increases over the critical levels. Previously Savin et al. (2009) and (Akpinar and Ortas, 2023) reported that increasing P fertilization reduced mycorrhizal infection in cotton and maize plants. Moreover, Martínez-Medina et al. (2011) also, reported that reduced fertilizer dosage increases AM root colonization by *Funneliformis constrictum* or *Rhizophagus intraradices*. These studies support our research findings.

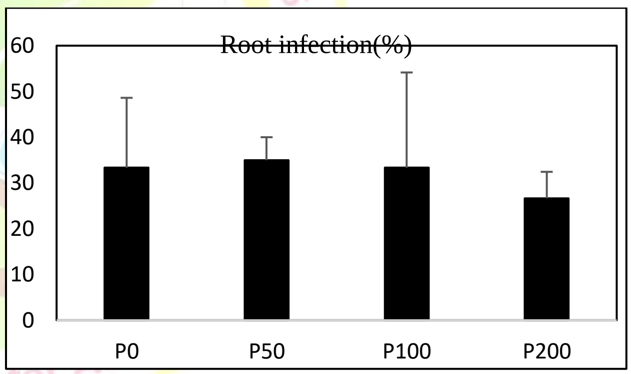

Figure 1. Effect of increasing P application on root infection.

P0 (Control), P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

Dry Matter Yield

The impact of increasing doses of P application upon dry matter yield of different parts of soybean is shown in Table 2. Shoot (P<0.0019) and seed (P<0.0010) were found to be statistically significant. It is seen that increasing doses of P application increased the growth and yield of different parts of soybean (especially above-root parts and grain). It is expected that the yield of the plant will increase as phosphorus fertilization increases. For example; previously in the same field experiment area, Işık et al. (2021) investigated the effect of increasing doses of P application on maize plant nutrition, yield and P utilization efficiency. In this study,

it was observed that increasing doses of P application increased maize yield.

It was observed that increasing doses of P application increased soybean yield. Similarly, Akpinar and Ortas (2023) reported that increasing doses of P application increased wheat yield in the same experimental area as well. Their studies support our research findings. In addition, Table 4 shows that there is a positive (0.922) correlation between shoot %P and seed yield. There is also a positive correlation between root %P and seed yield (0.815).

Table 2. Effect of increasing P application on root, shoot and seed DMY

Doses	Root	Shoot	Seed
	(kg ha^{-1})		
P0	1361±804	1361±804	1361±804
P50	1906±587	1906±587	1906±587
P100	1637±339	1637±339	1637±339
P200	1754±445	1754±445	1754±445
	NS	**	***

NS (as not significant), *, ** and *** show significant levels at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$. P0 (Control), P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

Nutrient Concentrations of Different Parts of Soybean

The effect of increasing doses of P application on the P, K and Zn concentrations of different parts of soybean is shown in Table 3. Phosphorus application at different doses did not create a statistically significant difference in terms of soybean plant mineral nutrient concentrations.

The effect of different phosphorus doses on the % P content of the plant was found statistically significant in seed (P<0.0050), shoot (P<0.0001) and root (P<0.0012) parts. The concentration of P in soybean tissues raised with increasing P application dosas. In general, P concentration in P0 treatments was below the critical value of 0.20% (Jones, 2012), whereas it increased with increasing P application in other treatments. A similar situation was observed in the findings of the study carried out by Akpinar and Ortas (2023) in the same research area, where increasing doses of P application increased wheat P uptake. However, there was no significant difference in the %K concentrations of different plant parts, while Zn concentration tended to decrease with increasing P dose application (Table 3). In the present work, plant parts Zn concentration seems to be higher than expected. In general, N2-fixing plants have a higher micronutrient than other plant species. Zn content of plant tissues increased with increasing P in grains, but Zn concentration in above-root axils decreased with increasing P fertilizer. The decrease may be due to the antagonistic relationship between P and Zn (Marschner, 2012). It is known that P fertilization forms a P-Zn compound with the Zn element (Schnug and De Kok, 2016). Moreover, Table 4 shows that there is a positive (0.859) correlation between shoot and root %P. In addition, there is also a positive (0.924) correlation between root and seed %P.

Table 3. Effect of increasing P application on different plant parts nutrition concentration

Doses	%K	%P	Zn (mg kg^{-1})
	Seed		
P0	0.80±0.03	0.17±0.04c	58.00±10.60
P50	0.90±0.04	0.38±0.02b	68.65±14.35
P100	0.88±0.04	0.43±0.02ba	67.45±4.75
P200	1.02±0.20	0.56±0.18a	70.90±1.7
	NS	**	*NS*
	Shoot		
P0	1.10±0.11	0.15±0.04c	64.03±5.46
P50	1.24±0.11	0.23±0.11b	65.30±7.42
P100	1.08±0.13	0.45±0.06a	54.17±2.06
P200	1.33±0.07	0.51±0.03a	62.10±13.83
	NS	***	*NS*
	Root		
P0	0.44±0.20	0.06±0.01c	11.05±0.55a
P50	0.34±0.12	0.17±0.02b	9.97±0.40b
P100	0.58±0.50	0.18±0.18a	11.35±0.15a
P200	0.44±0.11	0.16±0.09ba	9.63±0.25b
	NS	**	**

NS (as not significant), *, ** and *** show significant level at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$. P0 (Control), P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

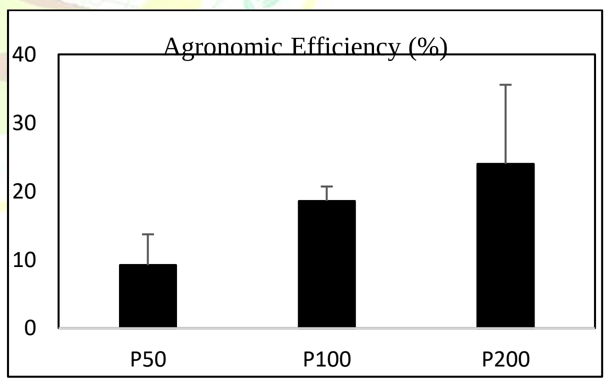

Figure 2. Effect of increasing P application on AE P50 (50 kg P_2O_5 ha^{-1}), P100 (100 kg P_2O_5 ha^{-1}), P200 (200 kg P_2O_5 ha^{-1}).

Agronomic Efficiency

The effect of increasing doses of P application on AE is shown in Figure 2. The highest AE was observed in the P100 and P200 kg ha^{-1} treatments. However, there was a statistically significant difference between the P dose application. In general, compared to control treatments, increasing P fertilizer AE is increasing.

García and Salvagiotti (2010) applied four P doses (0, 100, 200 and 400 kg ha^{-1}) to soybean and AE was

calculated. AE was highest at 100 kg ha^{-1} P_2O_5 dose application and more P doses addition decreased the efficiency. Işık et al. (2021) investigated the effect of increasing doses of P application (such as 0, 50, 100 and 200 kg P_2O_5 ha^{-1}) on maize AE. It was reported that maize AE increased up to 100 kg P_2O_5 ha^{-1} and decreased at 200 kg P_2O_5 ha^{-1}. Vanlauwe et al. (2011) reported that fertilization decreased AE in his study.

Overall results shown that founded results support our hypothesis. Under field conditions, 100 kg ha^{-1} P_2O_5 dose application can be suggested for healthy soybean production.

CONCLUSIONS

Increasing doses of P fertilization increased the growth and yield of soybean plants under long-term P-applied experimental conditions. P fertilizer application also increased P uptake and AE. However, Zn concentration tended to decrease with increasing P application. The results show that 100 kg ha^{-1} P_2O_5 dose application seems to be the optimum application for soybean cultivation.

Table 4. Correlation matrix in between measured plant parameters.

	Root (kg ha^{-1})	Shoot (kg ha^{-1})	Seed (kg ha^{-1})	Root İnf.	Root K %	Root P %	Root Zn (mg kg^{-1})	Shoot K %	Shoot P %	Shoot Zn (mg kg^{-1})	Seed K %	Seed P %	Seed Zn (mg kg^{-1})
Root (kg ha^{-1})	1												
Shoot (kg ha^{-1})	0,463	1											
Seed (kg ha^{-1})	0,287	0,634	1										
Root İnf.	-0,118	-0,104	-0,141	1									
Root K %	0,056	0,161	-0,059	-0,704	1								
Root P %	0,394	0,772	0,815	-0,256	0,110	1							
Root Zn (mg kg^{-1})	-0,240	-0,434	-0,327	0,069	0,232	-0,547	1						
Shoot K %	0,330	0,410	0,457	0,053	-0,535	0,531	-0,653	1					
Shoot P %	0,245	0,710	0,922	-0,370	0,152	0,859	-0,250	0,405	1				
Shoot Zn (mg kg^{-1})	0,085	-0,128	-0,084	-0,016	-0,353	-0,351	-0,201	0,222	-0,170	1			
Seed K %	0,067	0,473	0,522	-0,025	0,014	0,686	-0,457	0,564	0,507	-0,225	1		
Seed P %	0,199	0,699	0,772	-0,219	0,089	0,924	-0,489	0,476	0,798	-0,492	0,592	1	
Seed Zn (mg kg^{-1})	0,473	0,471	0,325	-0,592	0,330	0,643	-0,263	0,381	0,572	-0,303	0,248	0,552	1

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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Characterisation of the biological cycle of plants from two types of *Desmodium adscendens* (sw.) plant material for domestication in Daloa (Cote d'Ivoire)

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ABSTRACT

Desmodium adscendens (Sw.), the wild plant used to treat diverse pathologies, is menaced by deforestation and herbicides. It needs to be domesticated, starting with a study of its biology to preserve it and also to ensure healthy seedlings. It is in this context that this study was carried out to study the biology of *Desmodium adscendens*. To this end, grains and stem cuttings harvested in the wild from the plantations were grown outside the field on a block system. This consists of three blocks, with each block constituting a replication. After the crop was planted, germination and budburst rates, and quantitative parameters (stem length, number of branches, spread and flowering rate) were determined at one, two and three months after sowing. In addition to these parameters, a number of morphological parameters were determined. The results showed that bud burst was faster than germination. Also, in terms of growth parameters, plants grown from stem cuttings obtained better values with a large difference compared to those grown from grains. In addition, plants grown from grainss have a longer growing cycle (90 days) than plants grown from stem cuttings, which have an average growing cycle of 49 days. Its morphological structure is similar to that of legumes, with indeterminate growth. However, propagation by grains or stem cuttings is possible, depending on the objectives set. In short, *Desmodium adscendens* can be used as a cover plant in agroforestry systems and for soil restoration.

Keywords: *Desmodium adscendens*, crops, phenological phase, Daloa, Côte d'Ivoire

INTRODUCTION

Deforestation impacts all tropical forests, especially in the Amazon, equatorial Africa, and Southeast Asia (Kouassi *et al*., 2015). From 1990 to 2020, the global forest area decreased by 178 million hectares (FAO & UNEP, 2020). Côte d'Ivoire is also affected; its forest cover declined from an estimated 16 million hectares in the 1900s (Chatelain *et al*., 2004) to approximately 2.97 million hectares in 2021 (Cuny *et al*., 2021), primarily consisting of classified forests, national parks, and reserves. Over the past decade, ongoing crises in Côte d'Ivoire have hindered the development of effective forest protection policies, resulting in illegal and uncontrolled occupation of protected areas (Kouassi *et al*., 2015). A direct result of deforestation is the decline or extinction of certain plant species. In light of threats to plant biodiversity, there is increasing interest in the domestication of wild species to conserve and develop under-utilized plant resources (Tenaillon *et al*., 2023). *Desmodium adscendens*, a native forage legume, is one such species being domesticated in the Daloa region of Côte d'Ivoire, where the soil and climate conditions support its cultivation (Kouadio *et al*., 2021; Lal, 2015). A thorough understanding of the biology of *Desmodium adscendens* during the domestication phase is essential to optimise the cultivation technique and improve its yield. This study therefore aims to assess the main biological traits of this species to be domesticated under the soil and climate conditions in Daloa. More specifically, the growth parameters of plants obtained from the two types of *Desmodium adscendens* planting material will be analysed, and the morphological characteristics of plants obtained from the two types of planting material will be described and identified. The results of this study will make it possible to identify the most relevant agronomic characteristics to be selected to develop a new *Desmodium adscendens* crop adapted to local needs, thus contributing to the supply of pharmaceutical industries interested in this plant.

MATERIALS AND METHODS

Study site

The experiment was carried out at the experimental farm of the Jean Lorougnon Guédé University in Daloa. Daloa is a town in central-western Côte d'Ivoire. The Daloa region is a forested area and is the capital of the Haut-Sassandra region (Koukougnon, 2020). Soils in the Daloa region are predominantly ferralitic. They are very deep with a high organic matter content. These ferralitic soils are suitable for agriculture and lend themselves to all types of crops (Soro *et al*., 2015).

Plant material

The plant material consisted of *Desmodium adscendens* grains and stem stem cuttings (Figure 1) collected from palm, cocoa and rubber plantations in Assouba (Aboisso, Côte d'Ivoire). This area is one of the major ecological zones where *Desmodium adscendens* grows naturally.

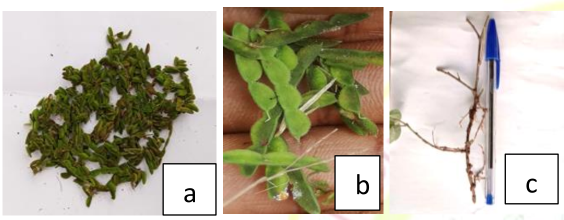

Figure 1: Plant material used
a & b: pods ; c: stump of *Desmodium adscendens*

Preparing the plot and setting up the trial

The experimental plot was prepared in two stages. The first involved clearing and weeding the plot using a machete. The second stage involved levelling the ground using a daba. The grainss and stem cuttings were sown in 5-litre buckets, the bottoms of which were perforated with a nail. The system used for the experiment was a block system (Figure 2). It is made up of three blocks, with each block constituting a repetition. Within each block, there are two sub-blocks, each containing 30 buckets in which the stem stem cuttings and grainss were grown. The sub-blocks are ten metres apart. The spacing between the buckets is 1 m.

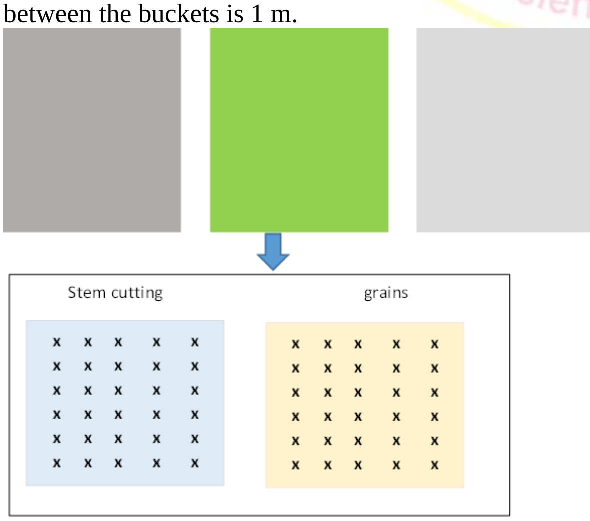

Figure 2. Experimental Dispositif
X : Buckets

Data collection

Germination and budburst parameters:

- Germination and budburst rates.

These rates were evaluated according to the following formula:

TG = (NGG/NTGS) X 100 ;

TD = (NBD/ NTB) X100

TG: germination rate; NGG: number of grains germinated; NTGS: total number of grains sown; TD: bud burst rate; NBD: number of stem cuttings burst; NTB: total number of stem cuttings.

- Germination and bud burst time.

This is the time (in days) that elapses between sowing and the total appearance of a seedling.

The germination and bud break capacity of stem cuttings has been expressed as a function of time.

Agromorphological parameters

Growth and development parameters such as stem length; number of branches; and plant spread were determined at one month (30 days), two months (60 days) and three months (90) after sowing. Flowering and fruit formation times were also determined. In addition to these parameters, the various phenological phases from germination to flowering were noted.

Statistical analysis

The data collected were processed using IBM SPSS software.

RESULTS AND DISCUSSIONS

Evaluation of the germination and budburst rate of *Desmodium adscendens*

The results of the evaluation of the germination and bud burst rates showed that five days after sowing, the stem cuttings had begun to bud (Figure 3). However, no germination was recorded in the seeds. On the 7th day after sowing, half (50%) of the number of seeds had germinated. By the 12th day after sowing, the maximum number of seeds and stem cuttings had germinated. However, budburst progressed more quickly than germination.

Growth parameters of plants grown from *Desmodium adscendens* stem cuttings and seeds at different dates after sowing

Stem length

The results showed that one month after sowing, the difference in size between plants grown from stem cuttings and those grown from seeds became apparent (Figure 4). The results showed that up to two months after sowing, plants grown from cuttings had long stems, unlike those grown from seed. However, from three months onwards, the difference between plants grown from stem cuttings and those grown from seeds became less significant. However, the stems of plants grown from stem cuttings developed faster.

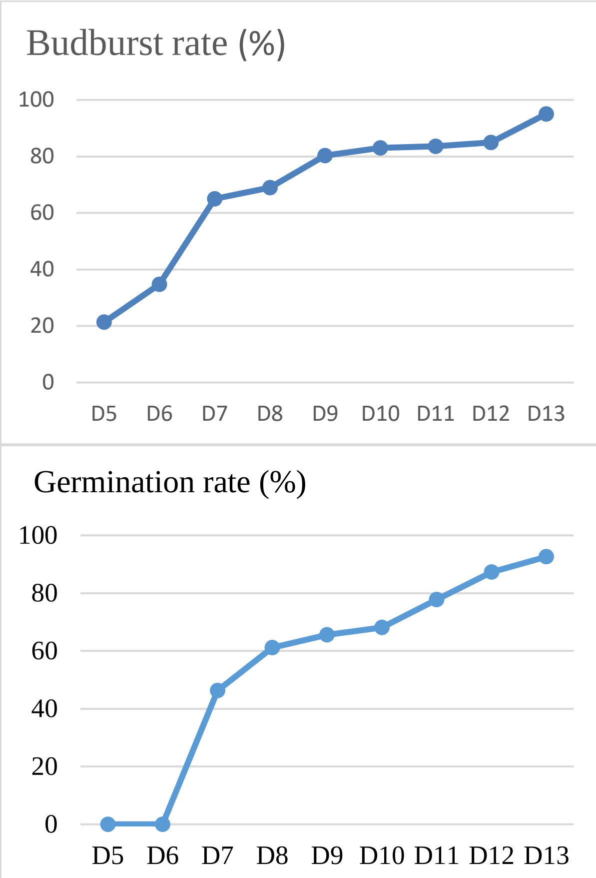

Figure 3. Curves of germination and budburst rate times (days) D: number of days after sowing

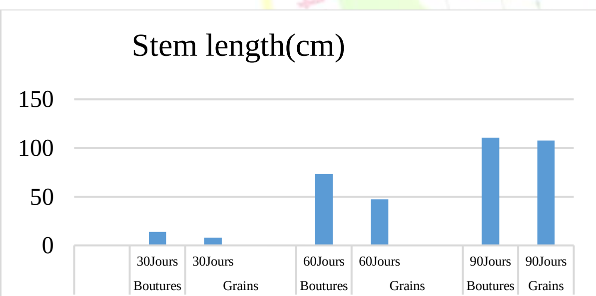

Figure 4. Histograms of stem lengths evolution
Boutures : stem cutting ; grains: seed and jours : days

Branches number

The results showed that there was little difference between the average number of branches (Figure 5). However, during the first two months, plants from stem cuttings recorded more branching. From three months onwards (90 days), the number of branches became greater in plants grown from seeds than in those grown from stem cuttings.

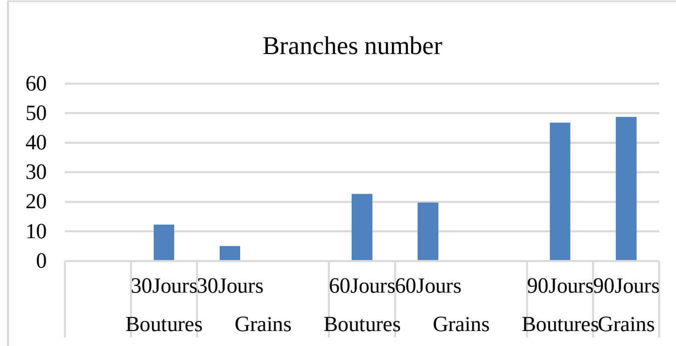

Figure 5. Histograms of changes in the number of branches
Boutures : stem cutting ; grains : seed and jours : days

Plants spans

The result shows the average span of plants grown from *Desmodium adscendens* stem cuttings and seeds over three months (Figure 6). The differences between the average sizes of plants grown from cuttings and those grown from grain were greater before the first three months. However, after three months, the difference observed between the average spans of plants grown from the two types of plant material became small.

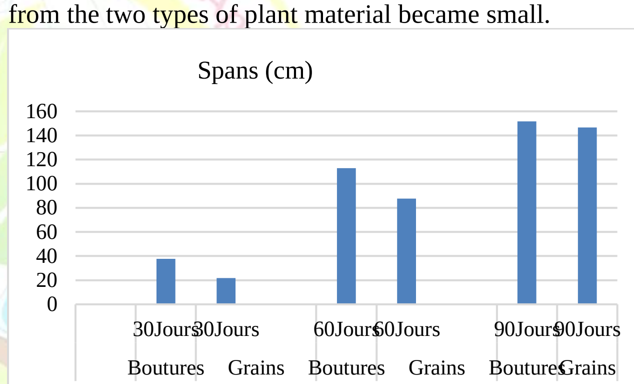

Figure 6. Histograms of changes in plant spans
outures : stem cutting ; grains : seed and jours : days

3.1.1.3. Flowering rate of *Desmodium adscendens*

The results show that plants grown from stem cutting are quick to flower, unlike those grown from seed (Figure 7). Thus, 50% of plants from stem cuttings flowered within 60 days compared with 115 days for plants from seeds.

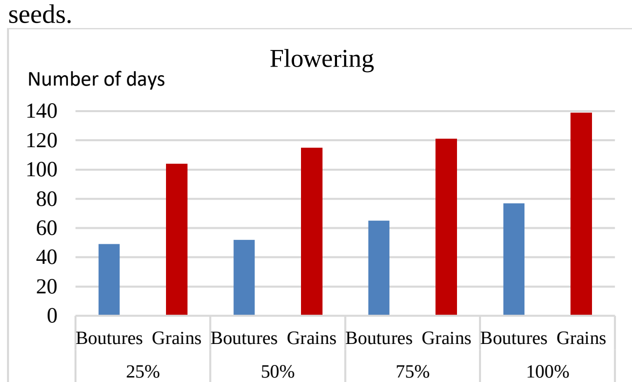

Figure 7. Flowering rate of plants grown from stem cuttings and seeds
Red histogram: stem cutting ; blue histogram : seed

Development cycle of *Desmodium adscendens*

The different phenological phases of *Desmodium adscendens* plants grown from stem cuttings and seeds were summarised according to the number of days after planting (Table I). Plants grown from stem cuttings had an average vegetative cycle of between 5 and 49 days, compared with a vegetative cycle of between 7 and 90 days for plants grown from seeds. The first flowers appeared on the 50th day with the stem-cutting plants. Plants grown from stem cuttings therefore have a shorter vegetative cycle than plants grown from seeds.

Table I. Presentation of the different phenological phases of plants grown from two types of *Desmodium adscendens* plant material

Phenological phase	Duration of phenological phase (days)	
	Plant material	
	Stem cutting	Grains
Vegetative cycle duration	5-49	7-90
Budbreak / Germination	5-15	7-20
Growth	15-25	30-45
Ramification	25-49	45-60
Flowering	48-60	90-120
Fruiting	60-90	105-150
Resumption of growth	90 and more	150 and more

NB: *Desmodium adscendens* is a plant with indeterminate growth.

Morphological description of the vegetative organs of *Desmodium adscendens*

The *Desmodium adscendens* plant has a fasciculated root system, with abundant roots forming a dense network in the first soil horizons. The stem is creeping, up to two metres long. It is quadrangular in shape, and devoid of hairs, giving it a smooth appearance with knots and numerous branches extending from the base of the plant (Figure 8 e & f). The leaves are entire during the early stages of growth and become trifoliate, with oval-oblong leaflets after about a month after germination. The leaflets are 2 to 6 cm long. Unlike stem cuttings, which regenerate seedlings similar to adult plants (Figure 8 d), seeds germinate epigenetically (Figure 8 a) while developing a seedling with whole leaves (Figure 8 b). These leaves are smooth, circular and spherical (Figure 8 c).

Morphological description of the reproductive organs of *Desmodium adscendens*

The flowers of *Desmodium adscendens* are grouped in terminal or axillary clusters (Figure 9 a & b). They are papilionaceous, rose-purple and about 8 mm long. The calyx is gamosepal with five unequal lobes. The corolla has five petals, with a standard, two wings and a carina. It contains ten diadelphous stamens (9 fused and 1 free). The ovary is superect, surmounted by a style and a stigma. It develops after fertilisation to form the fruit. The fruits are flat, linear pods, 2 to 5 cm long, divided into monosperm segments that disarticulate at maturity with kidney-shaped, reddish-brown seeds (Figure 9 c, d, e & f). The pods have dense hairs that enable them to adhere to fur and clothing.

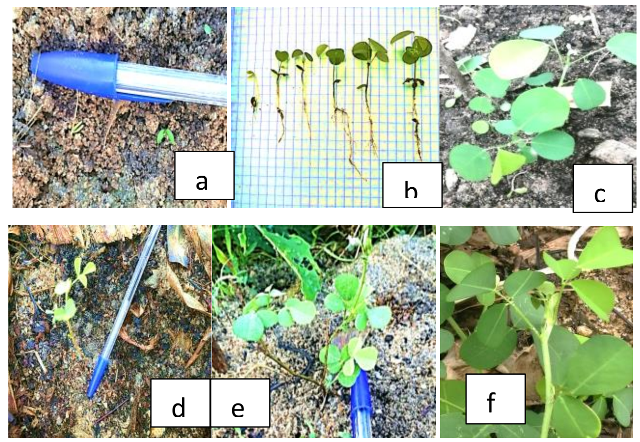

Figure 8. Presentation of the growth organs of *Desmodium adscendens*

a: germination; b & c: primary growth; d: bud burst; e: flowering of a plant from a stem cutting and f: elongation of the stem and formation of compound leaves.

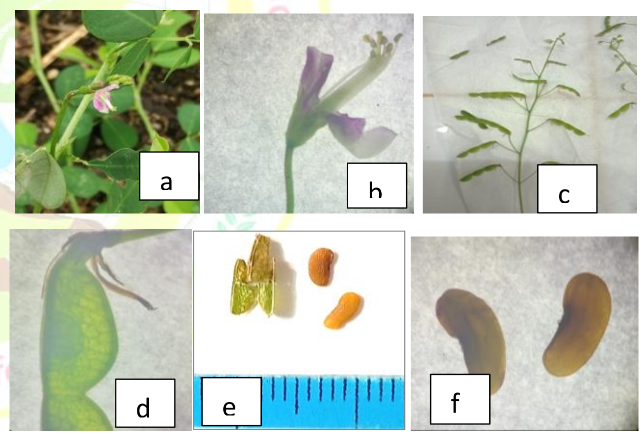

Figure 9. Presentation of the reproductive organs of *Desmodium adscendens*

a & b: presentation of the inflorescence; c & d: morphology of the pod and e & f: morphology of the seed.

Germination time and bud burst time were significantly different. The delay was shorter for stem cuttings than for seed. These results could be explained by the fact that sown stem cuttings have a higher hormonal balance than seeds. In addition, stem cuttings have meristems in the axillary buds (Véronique *et al.*, 2021). Also, regular irrigation and soil rich in organic matter are factors that can encourage early rooting of cuttings, while leading to their observed rapid bud burst (Bah *et al.*, 2021). On the other hand, the delay in germination is linked to integumentary dormancy induced by the rigidity of the

endocarp, which can constitute a physical barrier to the imbibition of the embryo, to gas and respiratory exchanges and the emergence of the radicle (Lompo *et al*., 2019). Seed dormancy can hurt germination rates (Rajib *et al*., 2023). Similar results were obtained by Joseph *et al*. (2023) on seeds of *Guibourtia tessmannii* (Harms) JL. of the Fabaceae-Cesalpinioidae family. These authors reported that seeds with a pericarp germinated with difficulty compared to those without a pericarp. On the other hand, Božena *et al.* (2024) reported that *Amorpha fruticosa* L. (Fabaceae) seeds sown without storage conditions germinated within a short time.

The results of the growth variables determined 45 days after sowing showed that the plants grown from stem cutting obtained better values than those grown from seed. This was due to the rapid bud break observed in the sown stem cuttings. In addition, the stem cuttings already contain sufficient quantities of certain growth hormones to have a positive impact on the speed of growth in these plants. Contrary results were obtained by Nguema *et al.* (2013) on Jatropha curcas L. According to their work, plants from Jatropha stem cuttings grow slowly compared with those from seeds. From 90 days after sowing, plants grown from seeds recorded better values for growth parameters. Plants grown from stem cuttings flow faster than those grown from seed. The stem cuttings already contain the same hormones as the original mother plant. Similar results were obtained by Nguema *et al.* (2013) on Jatropha Curcas L.

The study of the different phenological phases of *Desmodium adscendens* shows that this species has a rhythmic growth. It has a stem elongation phase lasting around 45 days and a secondary organ development phase. *Desmodium adscendens* is a species with indeterminate growth, and its cycle continues after fruiting. Naturally, it flowers during the summer. However, in cultivation, it flowers for three months and can flower as the branches develop under normal conditions. *Desmodium adscendens* has a fasciculated root system, with its roots forming nodules as it grows. This species belongs to the legume family and can be used in the same way as groundnuts, beans and soya to improve soil fertility. Its leaf morphology is similar to that of groundnuts, but the difference lies in the stem and fruit. Its fruits (pods) are articulated and hairy, just like those of Desmodium affine and other Desmodium species, enabling them to be spread by humans and wild animals (Freitas *et al*., 2014). The physical appearance of the seed shows that it is first covered by a very rigid shell and then by an inner integument. This aspect is thought to be responsible for the seed's resistance to biological aggressors and also helps to extend its lifespan. Consequently, the tegument may act as an inhibitor of the seed's metabolic reactions in sparse rainfall (Berghouti *et al*., 2022), and thus be responsible for its late germination.

CONCLUSION

The results of this study show that *Desmodium adscendens* can be propagated by cuttings as well as by seeds. However, vegetative propagation results in earlier bud break than germination, which is slow. This study revealed a first growth stage, characterised by the formation of whole leaves. The second stage was observed after a month, with the appearance of compound leaves and the formation of secondary organs. Plants grown from stem cuttings flowered more quickly than those grown from seed. In terms of flower morphology, the flower is structured in such a way as to avoid cross-pollination. But it should be noted that seed propagation would also be advantageous in terms of avoiding the persistence of certain contaminants in the plant.

In addition, this study opens up perspectives on the influence of environmental factors that could influence the growth and development of *Desmodium adscendens.*

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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Effects of Aphids on The Growth of Different Varieties of Indian Mustard

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ABSTRACT
The purpose of the experiment was to determine the prevalence of mustard aphids on various varieties of mustard in the field in Jassowala, Dehradun, Uttarakhand, from January to April of 2022. Three replications and a randomised complete block design were used to set up the experiment. The tolerant variations of eight mustard types, including T_1 (RH7859), T_2 (RH781), T_3 (RH785), T_4 (VARDHAN), T_5 (RH7847), T_6 (RH9006), T_7 (RH8546), and T_8 (VARUNA), were assessed against aphid infestation on plants, leaves, inflorescence, and pods. Regarding aphid infestation on plants, leaves, inflorescence, and pod, T_8 (VARUNA) was shown to be the most favoured host out of the eight varieties of mustard, whereas T_1 (RH7859), performed as the least preferred variety. T_1 (RH7859), the variety most vulnerable to aphids, yielded the lowest seed yield per plot and T_8 (VARUNA) seed yield with the least amount of aphid infestation. According to the study, the T_8 (VARUNA) produced the maximum yield and showed the least amount of aphid infestation. On the other hand, T_1 (RH7859), yielded the fewest seeds and displayed the most aphid infestation.
Keywords: Aphid, Mustard, Growth, Yield, Oilseeds

INTRODUCTION

Oilseeds are of nutritional importance and have been cultivated all over the world because of their great utilization in the agricultural system. Different oilseed crops are soybean, rapeseed, mustard, groundnut, peanut, cotton and sunflower considered important sources of edible oil in India (Anonymous, 2012). Indian mustard has been considered an essential oilseed crop since ancient times. The mustard crop is the main source of income for small farmers as this crop is commonly grown in the rain-fed region of the country and provides livelihood security (Jaglan *et.al.* 1988).

Different species of mustard are (*Brassica juncea*, *Brassica campestris*, and *Brassica napus* L.) grown in the Indian subcontinent. *Brassica napus* (Rapeseed-mustard) is regarded as the third most important oilseed crop around the world after soybean and palm oil. Around the world, 37.07 million hectares are used to grow rapeseed and mustard, with a yield of 73.27 million tons and productivity of 1976 kg per hectare (Thakur *et. al.*, 2009). On the other hand, 8.03 million tons of rapeseed are produced in India annually on 6.36 million hectares of land, with a yield of 1262 kg per hectare (Rangre *et. al.*, 2002).

India's rapeseed mustard productivity is still lower than the global average (1976 kg ha^{-1}). The states of Rajasthan, M.P., U.P., Haryana, and Gujarat comprise almost 86% of the total area planted with rapeseed. 32 thousand hectares of mustard are planted in Punjab, where it is produced on 41.8 thousand tons of grain and yields 1306 kg/hectare (FAO, 2004).

Numerous pests, such as the sawfly (*Athalia lugens* Kiug) and the mustard aphid (*Lipaphis erysimi* Kalt), are associated with the harvesting of mustard (Singh P and NB Singh, 2004). When there are only one or more females, the reproduction rates can range from 59 puppies each day to 76188 puppies overall (Singh P and NB Singh, 2005). Aphids cause stunting in plants, wilting of flowers, and obstruction of pod formation when they inhale sap from leaves, stems, inflorescences, and pods (Atwal and Dhaliwal 1997; Begum 1995 and Basky Z and Fónagy A 2007).

Effective methods of controlling agricultural crop pest insects other than pesticides are now very difficult to come across. To identify the mustard kinds that are susceptible to aphid infestation, an experiment was carried out with the following goals in mind.

To identify and study the life cycle of aphids on Indian mustard.

To observe or identify the infestation of aphids on Indian mustard and damage caused by aphids.

MATERIALS AND METHODS

The purpose of the experiment was to ascertain the incidence of mustard aphids on several mustard cultivars between January and April of 2022. The materials and techniques used to experiment are listed below. The three separate seasons at the experimental site were the pre-monsoon period, or hot season, from March to April, the monsoon season from May to October, and the winter season, which lasted from November to February. The climate at the location was subtropical. In Dehradun, Uttarakhand, meteorological data for temperature, relative humidity, and rainfall were collected for the experiment (Panda *et. al.*, 2004.). The experimental area's soil, which is alluvial and fertile, is a part of Dehradun. This particular plot contains rocky, sandy, clayey, and clayey elements. Its pH is 7.8, and its accessible K_2O, S and N contents are low (105.48 kg ha^{-1}, 8.39 kg ha^{-1}, 196.75 kg ha^{-1}, 11.86 kg ha^{-1}), organic carbon is at 0.40%, and available Zn is at 0.47 ppm (Bajia R. and Singh NN 2014.). The corresponding crop season rainfall in 2022 was 49.80 mm. In the soil testing lab, the properties of the soil beneath the experimental plot were examined.

Three replications were used in the Randomized Complete Block Design (RCBD) experiment having eight treatments- T_1(RH7859), T_2(RH781), T_3(RH785), T_4(VARDHAN), T_5 (RH7847), T_6 (RH9006) , T_7 (RH8546) and T_8 (VARUNA). The experiment was designed to disseminate all of the results of treatments. Each experiment has 24 plots with a size of 2.0 m 1.0 m. Urea, TSP, MoP, Gypsum, Zinc sulphate and borax were used as fertilisers for N, P, K, S, Zn and B, respectively. During the final preparation of the land, the complete amount of TSP, MoP, Gypsum, Zinc sulphate and borax was applied. At final ground preparation and 30 days after seed sowing, urea was applied in two equal instalments. Table 1 shows the fertilizer dose and manner of application (Anonymous, 1995).

Table 1. Dose and method of application of fertilizers in a mustard field.

Fertilizers	Dose(kg/ha)	Application (%)	
		Basal	Top Dressing
Urea	280	150	130
TSP	180	180	-
MP	100	100	-
Gypsum	180	180	-
Zinc Sulphate	100	100	-
Borax	100	100	--

The parameters which were measured at various time intervals which are -Total number of infested plants/plot, Total number of branch/plant, Total number of infested branch/plant, Total number of Aphid, Total number of silique/plants, Total number of infested silique/plants, Total number of seeds/silique, Weight of seeds/plant, Weight of silique/plants.

OPSTAT software was used to analyze and interpret the data. The data collected on various parameters was subjected to analysis of variance (ANOVA), significance level of 5% (Gomez KA and Gomez AA, 1984).

Figure 1. Experimental plot at the research field.

RESULTS AND DISCUSSION

Eight mustard varieties were evaluated against mustard aphids in the Rabi (winter) season of 2022 in the experimental field of Dehradun. The varieties are T1 (RH7859), T2 (RH781), T3 (RH785), T4 (VARDHAN), T5 (RH7847), T6 (RH9006), T7 (RH8546), and T8 (VARUNA). The study was carried out from January 1 to April 30, 2022, to identify the susceptible varieties against mustard aphids. The following subsections contain a presentation and discussion of the study's findings.

Effect of Aphids on Growth of Mustard Plants

Total number of infested plants/plots, Total number of branch/plant (%), Total number of infested branch/plant (%), Total number of aphids on mustard varieties etc are an important morphological characteristic of any crop and may vary from variety to variety under different stages. The effect of different aphids on a total number of infested plants/plots was studied in a mustard crop periodically at 20, 40, 60 and 80 days after sowing (DAS) during the year 2022 and is presented in Table 2 and Figure 2. The total number of infested plants/plots was observed to increase from 20 to 80 days. Significant variation was observed among the different varieties of mustard against infestation of aphids on them. The T1 treatment defined the highest number of infested

plants/plots as compared to other treatments. The T8 treatment had the lowest infestation at intervals of 20-80 days. At 80 days, a 50% infestation of aphid was evaluated. The data revealed that mustard crops easily get infested by aphids. The variety RH7859 of the mustard crop easily gets affected by aphids. With the increase in the number of day intervals, the infestation also increases. A significant incremented pattern is observed in all growth stages. The total number of branches/plants is an important morphological characteristic of any crop and may vary from variety to variety under different stages. Significant variation was observed among the different varieties of mustard with a total number of branches/plants. The T8 and T4 treatments defined the highest total number of branches/plants as compared to other treatments. The T8 and T4 treatments defined 21.67% of the total number of branches/plants at 80 days. The treatment had the lowest total number of branches/plants at intervals of 20-80 days. The data revealed that the mustard crop had a large number of branches/plants. The mustard varieties VARUNA and VARDHAN had a high number of branches/plants. With the increase in the number of day intervals, the total number of branches/plants also increases. A significant incremented pattern is observed in all growth stages of mustard varieties. This suggests that the improper application of fertilizer doses decreased the total number of branches/plants in the mustard varieties. The total number of infested branches/plants was observed to increase from 20 to 80 days. Significant variation was observed among the different varieties of mustard with a total number of infested branches/plants. The T1 treatment defined the highest total number of infested branches/plants as compared to other treatments. The T8 treatment had the lowest total number of infested branches/plants at intervals of 20-80 days. At the 80 days 24.33% of the highest number of infested branches/plants was evaluated. The variety RH7859 of the mustard crop had a high number of infested branches/plants. With the increase in the number of day intervals, the total number of infested branches/plants also increases. A significant incremented pattern is observed in all mustard varieties. This suggests that the proper application of fertilizer doses had increased the total number of infested branches/plants in the mustard varieties. The total number of aphids was observed to increase from 20 to 80 days. Significant variation was observed among the different varieties of mustard with a total number of aphids. The T1 treatment defined the highest total number of aphids as compared to other treatments. The T1 treatment defined 19.67% of the total number of aphids at 80 days. The T8 treatment had the lowest total number of aphids at intervals of 20-80 days. At 80 days, 7.33% of the total number of aphids was evaluated. The data revealed that the mustard crop had a large number of aphids. The variety RH7859 of the mustard crop had a high total number of aphids. With the increase in the number of days intervals the total number of infested branches/plants also increases and a significant incremented pattern is observed in all mustard varieties. This suggests that the improper application of fertilizer doses had increased the total number of aphids in the mustard varieties. A similar result was obtained by Chandra et. al. (2013). The incidence of Lipaphis erysimi appeared on mustard commenced from 2nd S.W. and gradually reached its peak of 207.22, 262.89 aphid/10 cm central twig in 5 standard weeks, thereafter population started to decline significantly and reached its lowest 2.56, 0.44 in 6th S.W. during 2007-2008 and 2008-2009 crop seasons, respectively. The highest population of *L. erysimi* was observed in 4th and 5th S.W. from PRKS-14 (126.11 aphids) and PR-2006-14 (207.22 aphids), respectively during 2007- 2008 with the lowest zero from PBC-2005-3. Whereas during the 2008-2009 crop season, it was highest as on Ashirvad (174.00 aphid), Ashirvad (360.56 aphid) and lowest as on PRKS-28 (1.11 aphid), PRKS- 28 (4.11aphid) in 4th and 5th S.W., respectively. After the 5th S.W., the population of *L. erysimi* gradually declined due to an increase in temperature (Hasan and Singh, 2011).

The total number of silique/plants, total number of infested silique/plants, total number of seeds/silique, weight of seeds/plant and weight of silique/plant of any crop may vary from variety to variety under different stages. The total number of silique/plants was studied in mustard crop varieties periodically at 20, 40, 60 and 80 days after sowing (DAS) during the year 2022 and is presented in Table 3 and Figure 3. The total number of silique/plants was observed to increase from 20 to 80 days. Significant variation was observed among the different varieties of mustard with a total number of silique/plants. The T8 treatment defined the highest total number of silique/plants as compared to other treatments. The T8 treatment defined 8.67% of the total number of silique/plants at 80 days. The T1 treatment defined the highest total number of infested silique/plants as compared to other treatments. The T1 treatment defined 6.67% of the total number of infested silique/plants at 80 days. The T8 treatment had the lowest total number of infested silique/plants at intervals of 20-80 days. The data revealed that the mustard crop had a large number of infested silique/plants. The variety RH7859 of the mustard crop had a high total number of infested silique/plants. The less fertilizer dose application, not proper dose management causes the higher total number of infested silique/plants on mustard crop. With the increase in the number of days intervals, the total number of infested siliques/plants also increases. A significant incremented pattern is observed in all mustard varieties. This suggests that the improper application of fertilizer doses had increased the total number of infested siliques/plants in the mustard varieties. The T8 treatment defined the highest total number of seeds/siliques as compared to other treatments. The T8 treatment defined 14.99% of the total number of seeds/siliques at 80 days. The T1 treatment had the lowest total number of infested silique/plants at

intervals of 20-80 days. The data revealed that the mustard crop (T8) had a large number of seeds/siliques. The weight of seeds/plants of any crop may vary from variety to variety under different stages. The weight of seeds/plant was studied in mustard crop varieties periodically at 20, 40, 60 and 80 days after sowing (DAS) during the year 2021-22 and is presented in Table 3 and Figure 3. The weight of seeds/plant was observed to increase from 20 to 80 days. Significant variation was observed among the different varieties of mustard with the weight of seeds/plant. The T8 treatment defined the highest weight of seeds/plants as compared to other treatments. The T8 treatment defined 2.79 % of the total weight of seeds/plant at 80 days. The T1 treatment had the lowest weight of seeds/plant at intervals of 20-80 days. Significant variation was observed among the different varieties of mustard with the weight of silique/plant but the T8 treatment defined the highest weight of silique/plant (3.83%) as compared to other treatments. The T1 treatment had the lowest weight of silique/plant (3.43%) at intervals of 20-80 days. The data revealed that the mustard crop had the large weight of silique/plant. The variety RH7859 of the mustard crop had the low weight of silique/plant. The less fertilizer dose application, not proper dose management causes the more weight of silique/plant on the mustard crop. With the increase in the number of day intervals the weight of silique/plant also increases. A significant incremented pattern is observed in all mustard varieties. This suggests that the improper application of fertilizer doses had decreased the weight of silique/plant in the mustard varieties. Findings of this experiment are in accordance with the results obtained by Rana and Pachauri, 2001) and Guohuai et al., (2002). Based on the intrinsic rate of increase ‘rm’ it can be concluded that B. juncea was the most suitable oleiferous Brassica for *L. erysimi* while development on E. sativa was least suitable. The field condition prevailing in the year 2008-09 was most suitable but 15^{0}C temperature and 6h light duration was least suitable for *L. erysimi* growth and development (Hasan and Singh, 2015).

Table 2. Effect of Aphids on Growth of Mustard Plants

Treatment	Total number of infested plants /plot	Total number of branch /plant	Total number of infested branch /plant	Total number of aphids on mustard varieties
1	44.670±0.279	17.000±0.114	24.330±0.570	19.670±0.071
2	34.000± 0.849	18.000±0.349	20.000±0.428	13.000±0.200
3	37.670±0.504	19.670±0.301	23.000±0.044	14.670±0.253
4	43.330±0.011	21.670±0.553	23.670±0.417	18.330±0.069
5	25.670±0.427	17.330±0.316	19.330±0.251	7.670±0.076
6	34.670±0.812	19.670±0.348	20.670±0.398	13.670±0.128
7	40.670±1.037	20.670±0.344	23.330±0.218	15.670±0.106
8	24.670± 0.203	21.670±0.485	18.330±0.008	7.330±0.170
C.D.	1.851	1.18	0.948	0.484
SE(m)	0.604	0.385	0.309	0.158

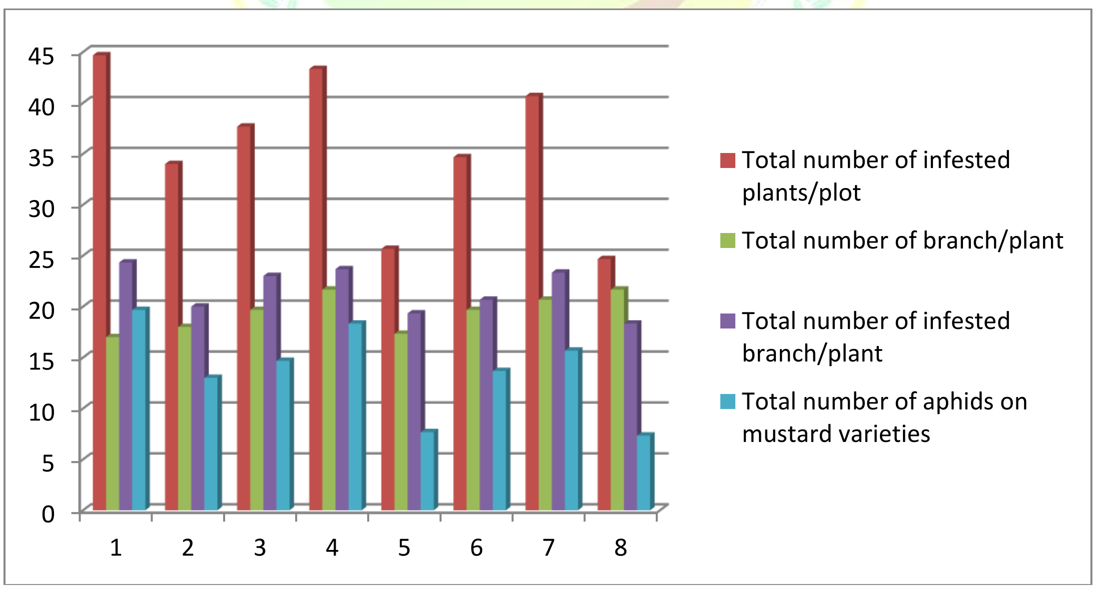

Fig 2. Effect of Aphids on Growth of Mustard Plants

Table 3. Effect of Aphids on Growth of Mustard Plants

Treatment	Total number of silique/ plants	Total number of infested silique /plants	Total number of seeds /silique	Weight of seeds/plant	Weight of silique/plant
1	4.330±0.026	6.670±0.059	9.670±0.149	2.240±0.027	3.430±0.035
2	5.670±0.071	2.670±0.067	12.670±0.056	2.250±0.045	3.550±0.035
3	6.670±0.036	4.330±0.002	13.330±0.038	2.280±0.006	3.580±0.064
4	7.330±0.070	5.670±0.043	14.670±0.362	2.360±0.049	3.600±0.009
5	5.330±0.011	2.670±0.001	10.670±0.217	2.290±0.026	3.640±0.072
6	6.330±0.089	3.670±0.044	13.670±0.306	2.590±0.018	3.710±0.042
7	7.670±0.000	5.330±0.042	14.670±0.275	2.700±0.027	3.760±0.033
8	8.670±0.113	1.670±0.006	14.99±0.362	2.790±0.015	3.830±0.094
C.D.	0.203	0.126	0.635	0.094	0.174
SE(m)	0.066	0.041	0.204	0.031	0.057

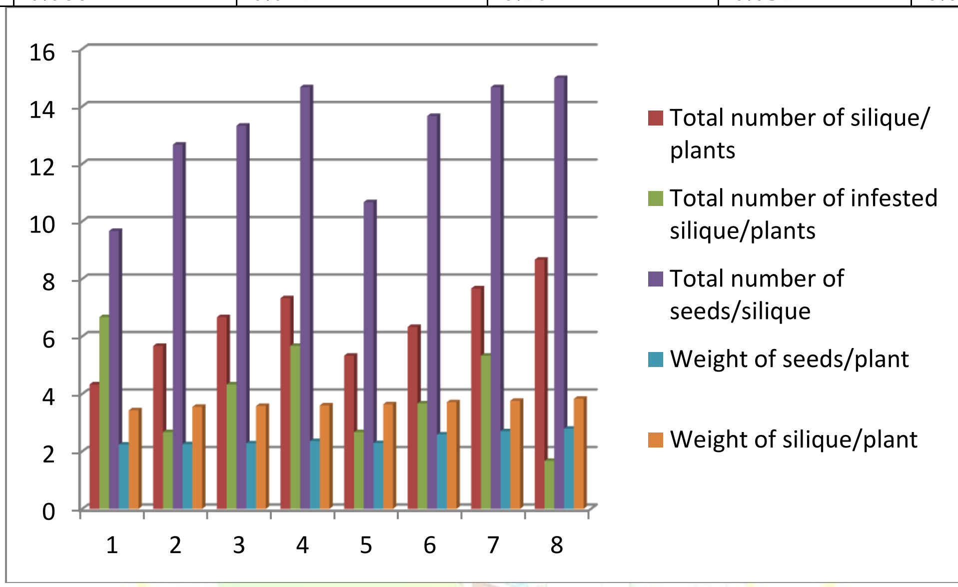

Fig 3. Effect of Aphids on Growth of Mustard Plants

CONCLUSION

The study's findings suggest that T_8 (VARUNA) had a lower incidence of mustard aphid infestation. In T_8, a lower aphid infestation was correlated with increased branch/plant numbers. According to this study, all of the types were essentially aphid-infested and prone to aphid attacks, yet T_8 was determined to be less susceptible. The findings underscore the importance of selecting mustard cultivars with enhanced resistance to aphids. The study provides a foundation for future research and cultivar development aimed at mitigating the impact of Aphids on mustard crops. Sustainable and environmentally friendly pest management practices, including the identification of resistant cultivars, are crucial for ensuring the productivity and quality of Indian mustard crops. Continued efforts in this direction can contribute significantly to the development of resilient agricultural systems.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

OPEN ACCESS

Impact of Climate Change on Biodiversity of Grasshoppers (Orthoptera: Acrididae) in Koshi Division of Bihar, India

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ABSTRACT
Bihar has been facing the most fluctuating climate change for years, especially the Koshi division, which comprises the three districts i.e, Saharsa, Madhepura and Supaul. Koshi River flows through and around the districts, affecting the area when water is released from the Nepal barrage. Thirty-two species of grasshoppers under twenty genera and ten subfamilies have been reported from the area of research. A maximum of eight species are represented by the subfamily Oedipodinae, while least one species is represented by the subfamily Spathosterninae. The main host is rice and maize among crops and grasses. Simpson's Diversity index calculated is 0.97, indicates rich diversity of grasshoppers and suggests a stable site. Population density is recorded highest at 30°C temperature and 50% humidity where reproduction and survival rates are maximum. Moderate rainfall stimulates plant growth, providing abundant and high quality food which in turn also favours population growth.
Keywords: Grasshoppers, Koshi division, Bihar, Diversity, Simpson's, Climate

INTRODUCTION
Orthoptera is the sixth largest order of insect constituting 22,500 species (Ghosh and Sengupta, 1982) all over the world out of which 1,750 species, 400 genera and 21 families are known from India (Tandon and Hazra, 1998). It is divided into two suborders ensifera and caelifera (Ander, 1939). Members of the suborder caelifera are commonly known as short-horned grasshoppers. Superfamily Acridoidea comprises 11,000 species worldwide and 290 species from India (Shishodia et al. 2010). Family Acrididae is the largest and most diverse family of the order Orthoptera shows 8,000 species with 136 endemic species (Chandra and Gupta 2013), are characterized by their relatively short, robust antennae, powerful hind legs adapted for jumping, with a variety of colours and variable body sizes.

Members of Acrididae play significant ecological and economic roles. Ecologically, they are primary consumers that feed on a wide range of grasses and herbs, influencing vegetation structure and nutrient cycling (Mulkern 1967). Economically, this cause loses to crops and act as notorious agricultural pests worldwide (Joshi et al. 1999). Many of these grasshoppers are highly specialized in their habitat and food preferences, making them sensitive to environmental changes. As a result, they are often used as bioindicators to assess the ecological health of their environments (Joern, A. 1979).

The Koshi division of Bihar, located in the eastern part of India, supports a variety of grasshopper species due to its complex mosaic of habitats and climatic conditions. However, despite their ecological importance, grasshopper diversity in this region remains understudied with some sporadic work. Despite these favourable conditions, studies on the diversity and ecology of grasshoppers in Bihar remain limited. Most of the available research focuses on economically significant species, while the broader taxonomic and ecological diversity of grasshoppers is underexplored (Singh and Singh, 2010). Thirty-seven species of grasshoppers representing twenty-nine genera have been reported from Bihar (Nayeem et al 2013) and 14 species of grasshoppers representing ten genera have been reported from Patna districts only (Tabrez and Nayeem 2024). Understanding the species composition and distribution of grasshoppers in the Koshi division is essential for ecological monitoring, pest management and biodiversity conservation. This paper aims to document the diversity of grasshoppers in the Koshi division of Bihar, highlighting their taxonomic composition, habitat preferences, and ecological significance. By providing a comprehensive inventory of grasshopper species in this region, the study seeks to fill a critical gap in the understanding of Orthopteran biodiversity in eastern India.

Weather is the most important factor determining the grasshopper population. Moderate increases in temperature can promote grasshopper population growth, extreme deviations negatively affect populations. This balance is crucial in managing grasshopper outbreaks, especially in agricultural areas where they can cause significant crop damage. Temperature and humidity are important factors responsible for the grasshopper population fluctuation (Khan and Aziz, 1973). Hatching time is influenced by temperature, cool and wet conditions reduce hatching (Das and Ganguly, 2012). High populations fall in the moderate range (40–60% relative humidity) which supports their physiological processes. Grasshopper populations are highest in regions with moderate rainfall (20–50 mm) because a shower of rain helps in the hatching of eggs (Uvarov, 1977).

MATERIALS AND METHODS

Study area: (Fig. 1)

Bihar is a state located in the eastern part of India, sharing its borders with Nepal to the north and West Bengal to the east, Uttar Pradesh to the west, and Jharkhand to the south. The state is situated in the fertile Gangetic Plain, which makes it one of the most agriculturally productive regions in India. Koshi division of Bihar constitutes three districts Saharsa, Madhepura, and Supaul. These districts lie in the northeastern part of the state and are part of the Koshi region, named after the Koshi River, which is one of the major rivers flowing through this area. The terrain is mostly flat and fertile, making it suitable for agriculture and major crops include paddy, wheat, maize, pulses, and jute.

Saharsa is situated in the heart of the Koshi region. It is characterized by flat plains and is crisscrossed by various rivers and streams, primarily influenced by the Koshi River. The economy of Saharsa is largely agrarian, with a focus on crops such as paddy, wheat, maize, pulses, and sugarcane. Despite the challenges of flooding, the fertile soil allows for productive farming. Madhepura is located to the west of Saharsa and has a similar geographical setup. The region is affected by the flow of the Koshi River, which makes it vulnerable to floods. The landscape is primarily rural and agricultural. Agriculture remains the backbone of Madhepura's economy produces rice, wheat, maize, and vegetables. Supaul lies to the east of Saharsa and is close to the border with Nepal. It is also part of the flood-prone Koshi belt, with the Koshi Barrage located nearby. The district has a diverse landscape with rivers, agricultural fields, and some hilly areas and the economy is largely dependent on agriculture. The fertile land supports the cultivation of paddy, maize and pulses.

Collection:

Grasshoppers were collected monthly from different habitats like crops, grasses, and meadows through sweep nets during day time when the sun bakes them. Collections started from a fixed place and extended the site as per the need. From the sweep, net was transferred to killing jars to kill the adult grasshoppers using potassium cyanide soaked in cotton.

Preservation:

Immediately on arrival to the laboratory, killed grasshoppers were taken out, stretched and pinned on a stretching box. During stretching special attention was given to wings, antennae, legs and abdomen to display basic taxonomic characteristics. Pinned specimens were left for a week to dry and completely dried specimens were labelled and stored in standard entomological boxes with naphthalene balls to prevent the attack of ants and other insects.

Identification:

Identification of specimens was carried out under the stereoscopic dissecting binocular microscope using the identification keys of Dirsh (1965) and available literature.

Data analysis:

Simpson's Index of Diversity (D) is a quantitative measure of how many different species are present in a habitat and how evenly the individuals are distributed among those species. The index is often used in ecological studies to measure species diversity. The high value of D indicates a more diverse and stable environment, while a low value of D indicates an unstable and low diversity. Simpson's Index denoted as D whose value ranges from 0 to 1 where 0 represents infinite diversity and 1, no diversity. That is, the bigger the value of D, the lower the diversity. This is neither intuitive nor logical, so to get over this problem, D is often subtracted from 1 to give Simpson's Index of Diversity (1 - D).

$$D = 1 - \left(\frac{\Sigma\, n(n-1)}{N(N-1)} \right)$$

n = the total number of organisms of a particular species
N = the total number of organisms of all species

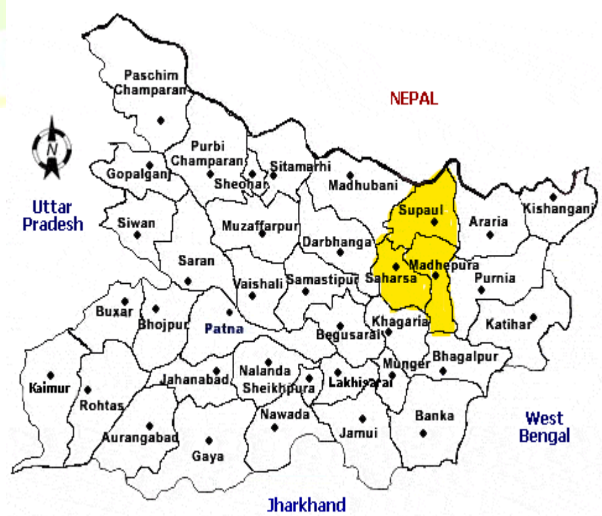


Fig. 1. Map of Bihar with highlighted Koshi division (Source- Google)

RESULTS AND DISCUSSION

Thirty-two species of grasshoppers under twenty genera and ten subfamilies have been reported from the area of research (Table 1). A maximum of eight species are represented by the subfamily oedipodinae followed by acridinae by four species while at least one species is represented by subfamily spathosterninae (Fig. 2). Main host is rice, and maize among crops and grasses. Simpson's index of 0.03 and Simpson's index of diversity calculated as 0.97, indicates that the area is showing more diversity of grasshoppers. A high value of D suggests a stable, complex and older site. A low value of D could suggest pollution, recent colonization or agricultural management. The value of D indicates the richness and evenness of the species found within the area sampled.

Temperature significantly influences the population dynamics of grasshoppers, as it affects their growth, reproduction, development, and survival. The maximum population of grasshoppers was recorded at 35°C temperature (Table 3). Humidity plays a significant role in shaping grasshopper populations as it affects their physiology and survival and the maximum population is recorded at a moderate range (40–60% relative humidity). Rainfall significantly influences grasshopper populations, both directly and indirectly, by affecting their habitat and food availability.

Research on Acrididae includes both agriculturally significant pests and ecologically important species and detailed study on their diversity, distribution and ecological roles can provide valuable insights for pest management and biodiversity conservation, particularly in agro-ecosystems where human and environmental interactions are intense. Grasshoppers are primary consumers of grasses and kin to predators) of in the food chain to balance the ecosystem (Branson et al. 2006). A study on the biodiversity of grasshoppers in the Koshi division of Bihar reveals a rich and diverse assemblage of species, underscoring the ecological significance of this region. This is an initial step toward documenting grasshopper diversity in the Koshi division and continuous research should include long-term monitoring, behavioural studies, and genetic analyses to better understand species adaptations and interactions. The region provides a home to generalist and specialist grasshopper species that reflect the unique agro-climatic conditions and habitat heterogeneity of the region. Grasshoppers exhibit habitat-specific preferences which indicates the importance of preserving diverse habitats to maintain ecological balance. The population of grasshoppers fluctuate with seasons, during monsoon and post-monsoon periods goes at peak than other seasons which is influenced by various climatic factors and types of vegetation.

Grasshoppers are ectotherms and their body temperature and metabolic processes depend on external temperatures. Warmer temperatures generally increase their metabolic rate, leading to faster growth and shorter life cycles but extremely high or low temperatures can stress grasshoppers and may cause mortality also. Grasshoppers thrive in low to moderate humidity, as these conditions mimic their preferred habitats dry conditions often favour egg survival in soil and promote faster development of nymphs. High humidity can negatively impact reproduction by creating unfavourable

Table 1. Number of species with subfamily and number of individuals

Species	Sub family	n	N (n-1)
Ochrilidia gracilis gracilis (Kraus, 1902)	Gomphocerinae	51	2550
Aulacobothrus luteipesluteipes (Walker, 1871)	Gomphocerinae	45	1980
Truxalis nasuta Linnaeus, 1758	Acridinae	102	10302
Acrida exaltata Walker, 1859	Acridinae	111	12210
Acrida gigantea Herbst, 1786	Acridinae	105	10920
Phlaeoba panteli Bolivar, 1902	Acridinae	96	9120
Phlaeoba infumata Brunner, 1893	Acridinae	90	8010
Oedaleus senegalensis Krauss, 1877	Oedipodinae	87	7482
Oedaleus abruptus Thunberg, 1815	Oedipodinae	93	8556
Aiolopus simulatrix Walker, 1870	Oedipodinae	87	7482
Heteropternis respondense (Walker, 1859)	Oedipodinae	78	6006
Oedipoda miniata Pallas, 1771	Oedipodinae	99	9702
Gastrimargus africanus Saussure, 1888	Oedipodinae	75	5550
Trilophidia repleta Walker, 1870	Oedipodinae	102	10302
Trilophidia annulata Thunberg, 1815	Oedipodinae	99	9702
Oxya fuscovittata (Marschall, 1836)	Oxyinae	123	15006
Oxya velox (Fabricius, 1787)	Oxyinae	126	15750
Oxya hyla hyla Serville, 1831	Oxyinae	87	7482
Oxya japonica japonica (Thunberg, 1815)	Oxyinae	81	6480
Hieroglyphus nigrorepletus Bolivar, 1912	Hemiacridinae	121	14520
Hieroglyphus banian (Fabricius,1798)	Hemiacridinae	108	11556
Spathosternum prasiniferum prasiniferum (Walker, 1817)	Spathosterninae	126	15750
Tristria pulvinata (Uvarov, 1921)	Tropidopolinae	66	4290
Tropidopola longicornis (Fieber, 1853)	Tropidopolinae	60	3540
Cyrtacanthacris t.tatarica (Linnaeus, 1758)	Cyrtacanthacridinae	72	5112
Chondacris rosea (De Geer, 1773)	Cyrtacanthacridinae	69	4692
Eyprepocnemis a. alacris (Surville, 1838)	Eyprepocnemidinae	63	3906
Heteracris littoralis (Rambur, 1838)	Eyprepocnemidinae	66	4290
Xenocatantops humilis (Serville,1838)	Catantopinae	78	6006
Xenocatantops karnyi (Kirby, 1910)	Catantopinae	90	8010
Diabolocatantops pinguis (Stal 1861)	Catantopinae	75	5550
Diabolocatantops innotabilis (Walker, 1870)	Catantopinae	72	5112
N=2797 N(N-1)= 7820412 Σ n(n-1)=306926			

conditions for egg incubation and increasing the risk of various pathogen infections. Grasshopper outbreaks are often linked to rainfall. During dry periods eggs remain dormant in the soil, and after rain mass hatching and rapid vegetation growth occur thus creates ideal conditions for population explosions.

Fig. 2. Subfamily and number of species

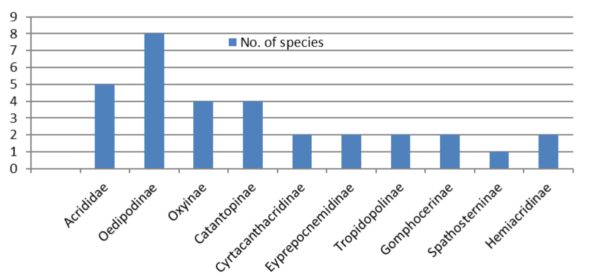
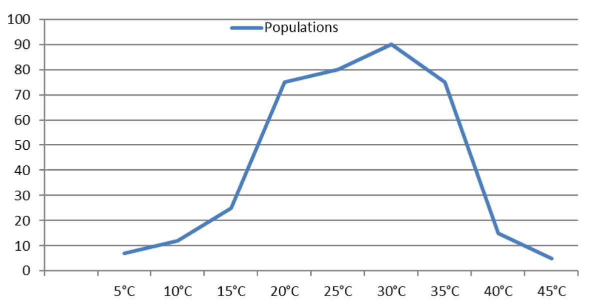


Fig. 3. Population (%) and temperature



CONCLUSION

The diversity and distribution of grasshoppers highlight the intricate interplay between species and their environments, decline in specific grasshopper populations may signal either habitat degradation or climatic shifts. The presence of specialist species in undisturbed habitats underscores the need for habitat protection. Grasshopper population dynamics reflect ecosystem health, making them valuable bioindicators. By bridging gaps in knowledge, this study serves as a foundation for ecological research, conservation strategies, and sustainable agricultural practices. Protecting grasshopper diversity is not only vital for maintaining ecosystem balance but also for supporting the livelihoods of local communities that depend on agriculture. The findings are expected to contribute to conservation strategies and the sustainable management of natural and agricultural ecosystems in the Koshi division.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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Research Article

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The effect of mycorrhiza-inoculated succession-planted main crop (maize-wheat) and cover crop rotation on soil organic carbon

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ABSTRACT
There has long been intense pressure on input-based traditional agriculture due to the rising need for food. These kinds of agricultural techniques result in poorly managed soil-plant interactions that ultimately affect all living activities and human health by altering and destroying the soil's natural structure, rendering it infertile, and degrading soil quality. Research was carried out a study to find out how mycorrhizae-inoculated cover crops affected soil quality and growth metrics. The study to pot experiment was carried out under greenhouse conditions. Five different plant combinations (cover crop) patterns were inoculated with selected and indigenous mycorrhizae spores that were isolated from the rhizosphere soils of plants grown in three degraded soils. Five different cover plant combinations, such as A: Clover, Grass, Onion; B: Faba Bean, Grass, Safflower; C: Clover, Grass, Safflower, Faba Bean, Onion; D: Maize; and E: Wheat, were planted in 7 kg soil-containing pots with three replications. The seeds of different plants were planted per m2 surface of each pot, with the number of seeds per pot calculated depending on their sowing amount per hectare. Sixty days after planting, the plants were harvested by cutting 0.5 cm above the soil surface with scissors. In the second rotation experiment, after the harvest of the first rotation experiment, maize (*Zea mays* L.) was planted on the A, B, C, and D patterns, and wheat was planted on the E pattern. In the third rotation, wheat was sown on all pots after the second maize harvest. As a result of successive three-pot experiments on the same soils, were analyzed for the soil organic carbon (SOC) concentrations. In general, treatments with Funneliformis mosseae followed by indigenous mycorrhiza spores led to an increase in soil OC concentration compared to control treatments. SOC concentrations in Havutlu and Arık soils were higher than those in Avadan soil. Avadan is a highly eroded soil and has high lime content, high pH, and low soil fertility. When consecutively planted trials are examined, the soil SOC concentration increased from the first trial to the last trial for all soils. The obtained SOC results seem to partially support the research hypothesis. The results revealed that poorly managed soil requires rehabilitations with various combinations of cover crops.
Keywords: Cover crops, Mycorrhizal inoculation, Wheat, Maize, Soil organic matter

INTRODUCTION

Soil is one of the most complex systems in the world due to its physical, chemical, and biological properties. Soils are the only source that provides 98.8% of our food. However, beyond expectations, agricultural soils, which constitute a very small part of the terrestrial ecosystem in the world, function as a living element despite being a limited resource (Ortas et al., 2021; Ortaş, 2017). While the human population increased from 250 million in 1000 to 6.1 billion in 2000, it is predicted to increase to 9.8 billion by 2050 (Kopittke et al., 2019). World population growth, which has doubled every 50 years in the last century, creates an increasing demand for food production on land. Currently, 42% of the world's population makes their living by farming, and agriculture determines the economies of many developing countries. For this reason, human life on our planet depends on sustainable agriculture (Aznar-Sanchez et al., 2019). Assumptions from the world's population show that in the 2050s, to meet food needs, demand will increase by 70% compared to the levels needed for human nutrition today, (Krishnan et al., 2020). With the increase in population, the growing need for agricultural products has been addressed by increasing the yield with intensive chemical fertilizers and pesticides. Unfortunately, the negative effects of excessive use of chemical inputs in agricultural activities, on human and environmental health, have accumulated over time. The increasing demand and consumption of food lead to the intensification of agricultural production and increased soil inputs to boost the soil per unit area, resulting in the rapid deterioration of soil quality and a decrease in its productivity.

As a result, sustainable agricultural systems that are based not only on increasing yields but also on protecting

human health and the environment have gained importance (Eryılmaz et al., 2019). In areas where agriculture has been carried out for years, inappropriate heavy soil tillage management, excessive chemical use, and monoculture have negatively affected the natural vitality of the soil. In agricultural areas where continuous monoculture is carried out, the unilateral decrease in certain mineral nutrients from the soil over time, the differentiation of certain microorganism communities (Börner and Özer, 2010) and especially the negative effects on organisms such as mycorrhizal fungi, and deterioration of the soil biological activity of the soil fatigue (Politycka, 2005). As expected, soil fatigue and poor soil quality reduce soil productivity or yield. To bring the soil back to a productive state, a series of special measures such as plant rotation, organic matter addition, and/or microorganism inoculations has been tried. Mycorrhizal fungi establish a symbiotic relationship with some plant roots (Compant et al., 2010; Schwartz et al., 2006) and provide nutrients (Harrison and van Buuren, 1995), while the plant provides carbohydrates (Javaid, 2009) for its energy supply (Smith and Read, 2010). Also, mycorrhiza protects the plants from stress factors and plays a unique role in the healing and balanced nutrition of soils. In this context, mycorrhizal fungi act as a bridge between the root and the soil and play an active role in the transportation of nutrients from the soil to the plant roots. Physiological and morphological changes occur in the plant roots with mycorrhizal inoculation; some events, such as competition, contribute to plant development (Yildiz, 2009).

In this context, various ecological practices or suggestions have been presented in recent years. For example, it is emphasized that many suggestions such as minimum tillage, crop rotation, cover crops and sensitive water/nutrient management have positive effects on soil fertility, increase soil biodiversity and improve carbon sequestration and nutrient storage, which directly influence sustainability (Jat et al., 2022). These mechanisms are necessary for sustainable agriculture.

The application of cover crops, to mixed cropping areas, and the natural mycorrhizal fungi in the soil, both of which are ancient natural mechanisms, are extremely important for sustainability. The application of these practices can restore the biological fertility of the soil. Cover crops and mycorrhizal fungi (MF) to can stimulate the recovery of degraded agricultural soil structure, soil quality can be improved, and the sustainability of the agroecosystem can be restored. Despite all this information, the effects of cover crops and their interactions with mycorrhizal fungal communities and the mechanisms of their adaptation to soil ecological conditions are still not very well known (Hontoria et al., 2019).

As a result of the use of the natural mechanisms of plants in soil improvement, understanding the potential of different plants to capture carbon in the atmosphere and release carbon in the subsoil is important. In addition, the storage of carbon released to the underground root zone is also an important research topic. The increase in the carbon stock, especially organic carbon, in the soil improves the quality and maintains the soil biological productivity. At the same time, the carbon stock contributes to decreasing atmospheric CO_2 concentrations. Ortas and Yucel (2020) reported that mycorrhizae inoculation significantly increased cover crop growth and mycorrhiza stimulated plant carbon fixation. In this way, sustainable agriculture mitigates climate change effects. In addition to selecting ideal cover crops suitable for each region according to land use, the accumulation of organic matter in the soil will improve the physical conditions and increase its biological richness, while also enhancing the chemical productivity and quality of the soil (Şimşekli and Kapur, 2012)

As a result of the increasing demand for food along with the increasing human population, This research is aimed to provide rehabilitation of soils by inoculating cover crops with mycorrhizae spores in three different types of soils where traditional agriculture with intensive input has been practised for many years; poor soil-plant management has been applied.

MATERIALS AND METHODS

Site and Experimental Descriptions

Experiments were established in three different poorly managed soils, with the 2-factor randomized plots experimental design in the Research and Application Greenhouses of the Soil Science and Plant Nutrition Department of the Faculty of Agriculture of Cukurova University.

The soil, mycorrhiza and plant types used in the experiment are as follows.

S1: Lands where long-term traditional agriculture is done (Havutlu, Yuregir/Adana) (Wheat-maize cultivation is done with a rotation system)

S2: Long-term continuous phosphorus application (Arık series, under 200 kg P_2O_5 ha^{-1} application in the University campus of Cukurova)

S3: Water-eroded soil unsuitable for agriculture (Avadan soil on the side of Tarsus/Mersin)

In terms of mycorrhiza, three different mycorrhizal inoculations were performed.

M1: Without Mycorrhizal inoculation

M2: *Funneliformis mosseae*: It is propagated in an alfalfa host plant medium. According to the spore count measurements in the medium before the trial, the number of Fu. mosseae spores was measured as 97 spores/10g medium.

M3: Indigenous mycorrhizae: Spores isolated from the rhizosphere soils of the plants, in the area, where all three mismanaged soils were collected, were obtained as a result of the multiplication of the host plants using trap culture management. The indigenous mycorrhiza counts of all three soils before the experiment are given in Table 1.

Five different plant patterns were planted on the inoculated soils, 3 plant patterns were cover plants, and the remaining 2 plant patterns were selected as regular rotation plants such as maize and wheat.
Cover crops and mixtures of these cover crops used in the experiments are such as;
Faba Beans (Luz de otono variety)
Alexandrian Clover
Italian Grass
Safflower
Onion
Maize (Kebeos maize variety)
Wheat (Adana 99 variety)
Grouping of cover crop patterns
A Plant pattern: Alexandrian clover, Italian grass, Onion.
B plant pattern: Faba Bean, Italian grass, Safflower.
C plant pattern: Alexandrian clover, Italian grass, Onion, Faba Bean, Safflower)
D plant pattern: Maize
Plant pattern E: Wheat
Some physical and chemical properties of the soils used in the experiment are given in Table 1.

Experimental Setup Description
Sterilized soil was filled into 7 L capacity pots and 3 different cover crops (A, B and C) were used as the D group plant along with maize (*Zea mays L.)* and wheat (*Triticum aestivum*) seeds were planted as group E. A total of 3 rotations were set up and conducted on the same soil-filled pots in succession. The experiment consisted of 135 pots with three replications. The trial design is shown in Figure 1.
In the first rotation trial, five different plant patterns were placed in the pots: A: Alexandrian clover, Italian grass, Onion; B: Faba Bean, Italian grass, Safflower; C: Alexandrian clover, Italian grass, Safflower, Faba Bean, Onion; D: Maize; and E: Wheat. Seeds of different plants corresponding to these patterns were planted.
In the second rotation trial, after the harvest of the first rotation trial, maize seeds were planted in the A, B, C, and D patterns in the same pots of five different plant patterns, and wheat seeds were planted again in the E group pots.
In the third rotation trial, only wheat seeds were planted in all pots after the maize and wheat plants were harvested.

Table 1. Some physical and chemical properties of the experimental soils.

Soil	Texture	Lime	Total N	Total C	OC	IC	K	Zn	F	Mn	Cu	Indigenous M. Spores
		%					Mg kg -1					Spore/10g soil.
T1 (Havutlu)	Clay Loam	15.31	0.15	-	-	1.84	184.63	0.27	3.97	2.79	1.74	95
T2 (Arik)	Clay Loam	25.55	0.15	4.05	0.98	3.07	255.25	1.24	2.22	3.99	0.98	76
T3 (Avadan)	Silty Loam	46.03	0.13	5.59	0.07	5.52	53.38	0.15	0.73	0.75	0.31	46

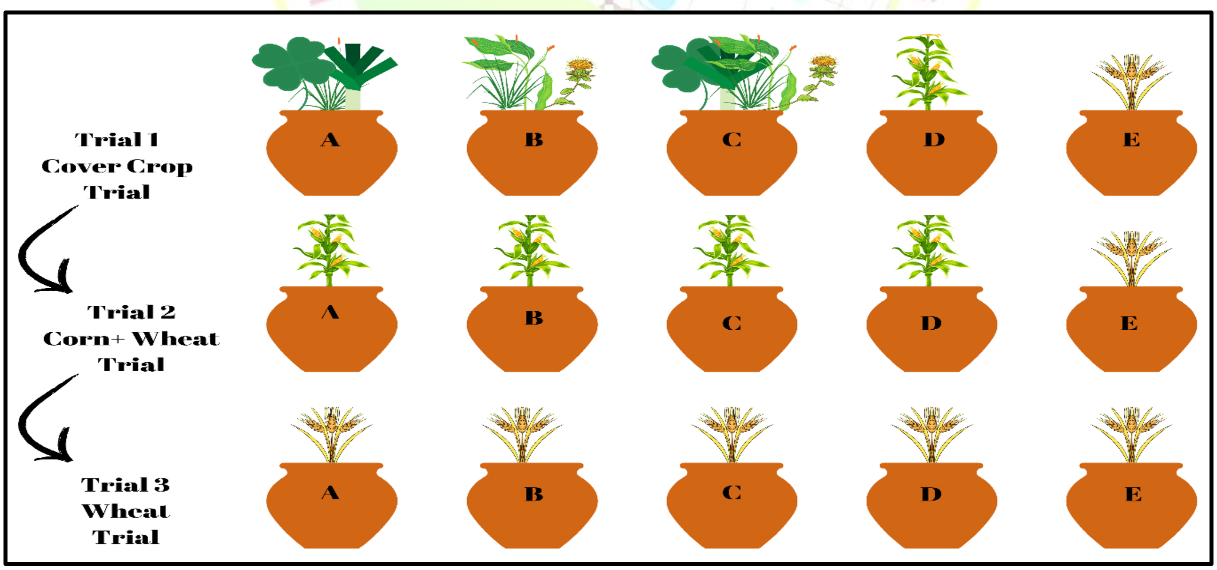

Figure 1. Rotation design of the experimental plots.

Harvesting Trials and Preparation for Analysis
A total of 1215 sample analyses were performed on plant and soil materials in 405 pots during the experiment, which consisted of 135 pots set up and finished in three stages in rotation. Within the scope of the research, 3 rotation trials were carried out, and these trials were planted and harvested.
In the first rotation trial, the cover crop was established on April 2, 2021, and harvested on May 23, 2021. The illustration of the trial is given in Figure 1.

In the second rotation trial, maize and wheat seeds were planted on June 11, 2021, and harvested on August 10, 2021. The rotation design of the trial is given in Figure 1. In the third and final rotation trial, the wheat seed planting was established on October 7, 2021 and harvested on December 14, 2021. The rotation design of the trial is given in Figure 1.

Chemical and Biochemical Properties of Soil

Total C (TC) were determined in oven-dried and <125-μm diameter fine soils using the CNS analyzer (Thermo-Fisher - 2000) according to the Dumas dry combustion method. To obtain soil organic carbon data, $CaCO_3$ was determined using a digital calcimeter, and inorganic carbon (IC) was obtained by subtracting $CaCO_3$ from total inorganic carbon.

Statistical Analysis and Interpretation

After the root, root surface, and rhizosphere soil samples of three rotation trials were analyzed and evaluated, the data for each rotation was recorded separately in the Excel data sheet. For the results of each experiment, ANOVA was performed using the JMP package program. The smallest differences between the applications were determined by the Tukey test.

RESULTS AND DISCUSSION

Soil Organic Carbon

Carbon that can be found in organic materials is known as soil organic carbon (SOC). Microorganisms, plant remnants, animal waste, and the byproducts of organic matter breakdown make up SOC. SOC is vital for soil health and fertility and contributes to the transformation and regulation of the atmosphere by participating in the carbon cycle. Under climate change conditions, keeping more soil organic carbon in the soil pool is vital for sustabanile soil management.

TOC is one of the parameters affecting soil fertility and helps provide the nutrients that plants need. It increases the ability of soils to retain and manage water, increases the aggregate stability of the soil, provides resistance to erosion, and contributes to the storage of carbon by withdrawing it from the atmosphere in the fight against climate change. Sustainable agricultural methods, organic fertilizers, cover crops, and correct soil management are critical to increasing soil organic carbon.

In this study, the effects of three different soils, three different mycorrhizae, and five different plant patterns on soil organic carbon content were investigated. The effects of three consecutive planting trials for each soil were considered separately. Data obtained for Havutlu soil 1 are presented in Figure 2, data obtained for Arık soil 2 are presented in Figure 3, and data obtained for Avadan soil 3 are presented in Figure 4. It appears that the prior rotation had an impact on the subsequent rotation, as three consecutive experiments were carried out after one another. This is crucial for the physical and biological fertility of soil as well as its overall health.

When the effects of successive planting trials on mycorrhizas inoculated into Havutlu soil (Figure 3.) soil organic carbon content was examined, the differences between the means in the mycorrhiza factor in the 2nd trial ($P<0.0448^*$) and in both the mycorrhiza ($P<0.0012^{**}$) and plant factor ($P<0.0001^{***}$) in the 3rd trial were found to be statistically significant.

When the TOC content was examined after the cover crop trial (Trial 1), the highest values were obtained as 1.7% for the interaction in the M3*E application, 1.62% for mycorrhiza in the M3 application and 1.62% for the plant pattern in the E plant pattern. When TOC content was examined after the maize+wheat trial (2nd Trial), the highest values were obtained as 1.79% for interaction in M3*D application, 1.63% for mycorrhiza in M3 application and 1.67% for plant pattern in D plant pattern. When TOC content was examined after the wheat trial (3rd Trial), the highest values were obtained as 2.48% for interaction in M2*E application, 2.21% for mycorrhiza in M2 application and 2.31% for plant pattern in E plant pattern. (Figure 2.)

When the effects of the trials planted consecutively on mycorrhizas inoculated into Arık soil (Figure 4) on TOC content were examined, the differences in mycorrhiza, plant pattern, and interaction values after the 1st and 2nd Trials in the data obtained were found to be statistically significant. When TOC content was examined after the cover crop trial (Trial 1), the highest values obtained were 1.44% for interaction in the M3*B application, 1.35% for mycorrhiza in the M2 application, and 1.35% for the B plant pattern. When TOC content was examined after the maize+wheat trial (Trial 2), the highest values were 1.62% for interaction in the M1*C application, 1.46% for mycorrhiza in the M1 application, and 1.44% in the B plant pattern. (Figure 3.)

The data of the infertile and eroded Avadan soil (Figure 4) were examined, and the differences in all other trials and applications except for the mycorrhiza*plant interaction and mycorrhiza factor in the averages observed in the second trial were found to be statistically significant. When TOC content was examined after the wheat trial, the highest values were obtained as 0.3% with interaction in the M2*D application, 0.26% with mycorrhiza in the M2 application, and 0.26% with plant pattern in the D plant pattern. (Figure 4.)

Examining the data obtained from experiments in three types of soil, indicated an increase is observed in the soil organic carbon content from the first to the third experiments. When the mycorrhizae inoculation effects were examined, it was observed that the effect of the selected species and indigenous mycorrhizae was positive compared to the control plants. Considering the organic carbon values in all three soils, the highest results are in Havutlu soil, and the lowest values are in Avadan soil.

The factors forming the soil organic carbon content are considered to include the plant roots remaining in the soil after each experiment, different secretions belonging to different plants, and microorganisms (mycorrhizae) as causal agents.

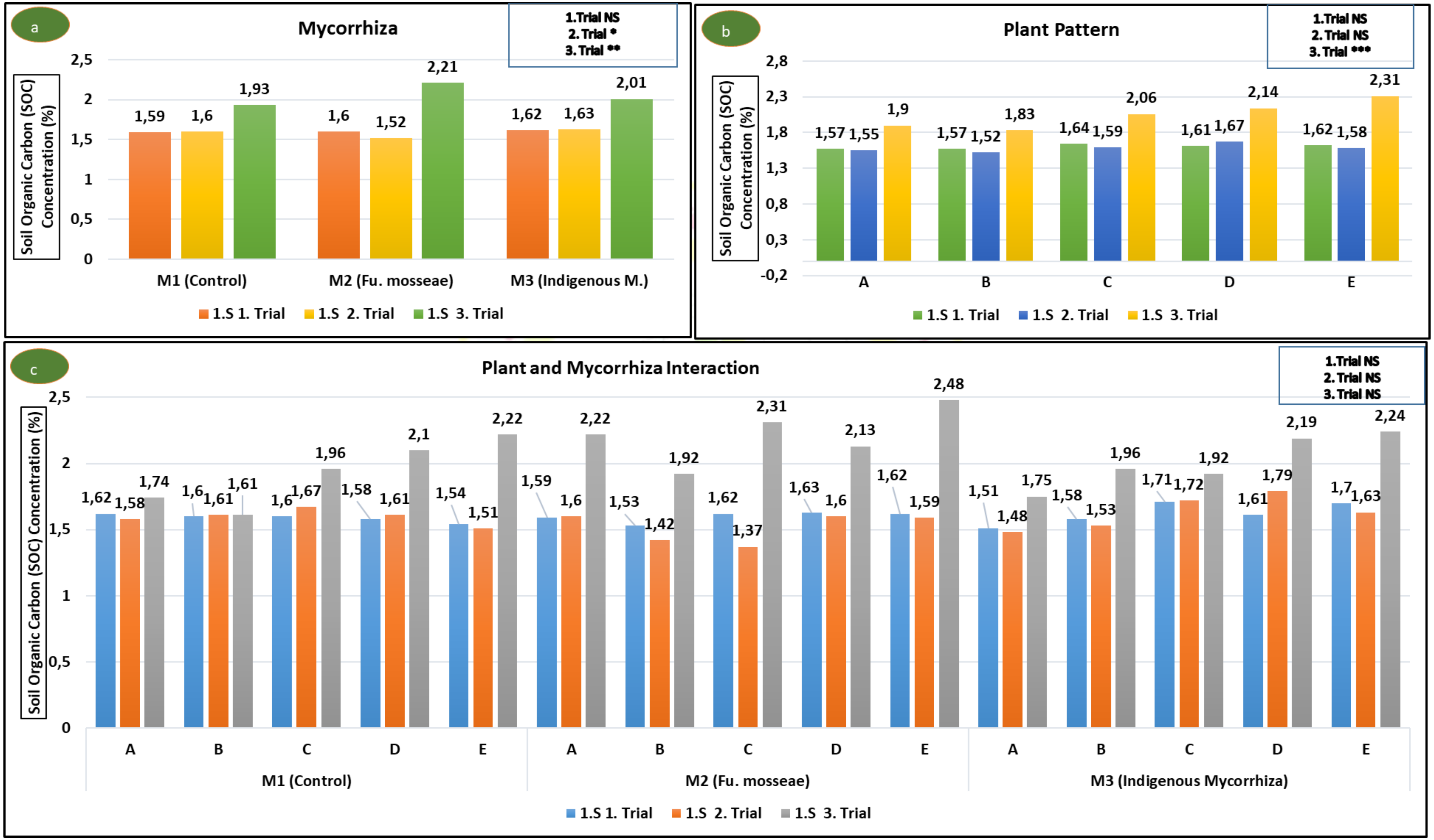

Figure 2. Change in organic carbon content in Havutlu soil, the first soil, as a result of 3 consecutive trials of different mycorrhiza inoculation and different cover crops. a: Averages of mycorrhiza applications b: Averages of plant patterns c: Averages of mycorrhiza*plant interaction NS: Non-significant *: p<0.05, **:p<0.01, ***:p<0.001

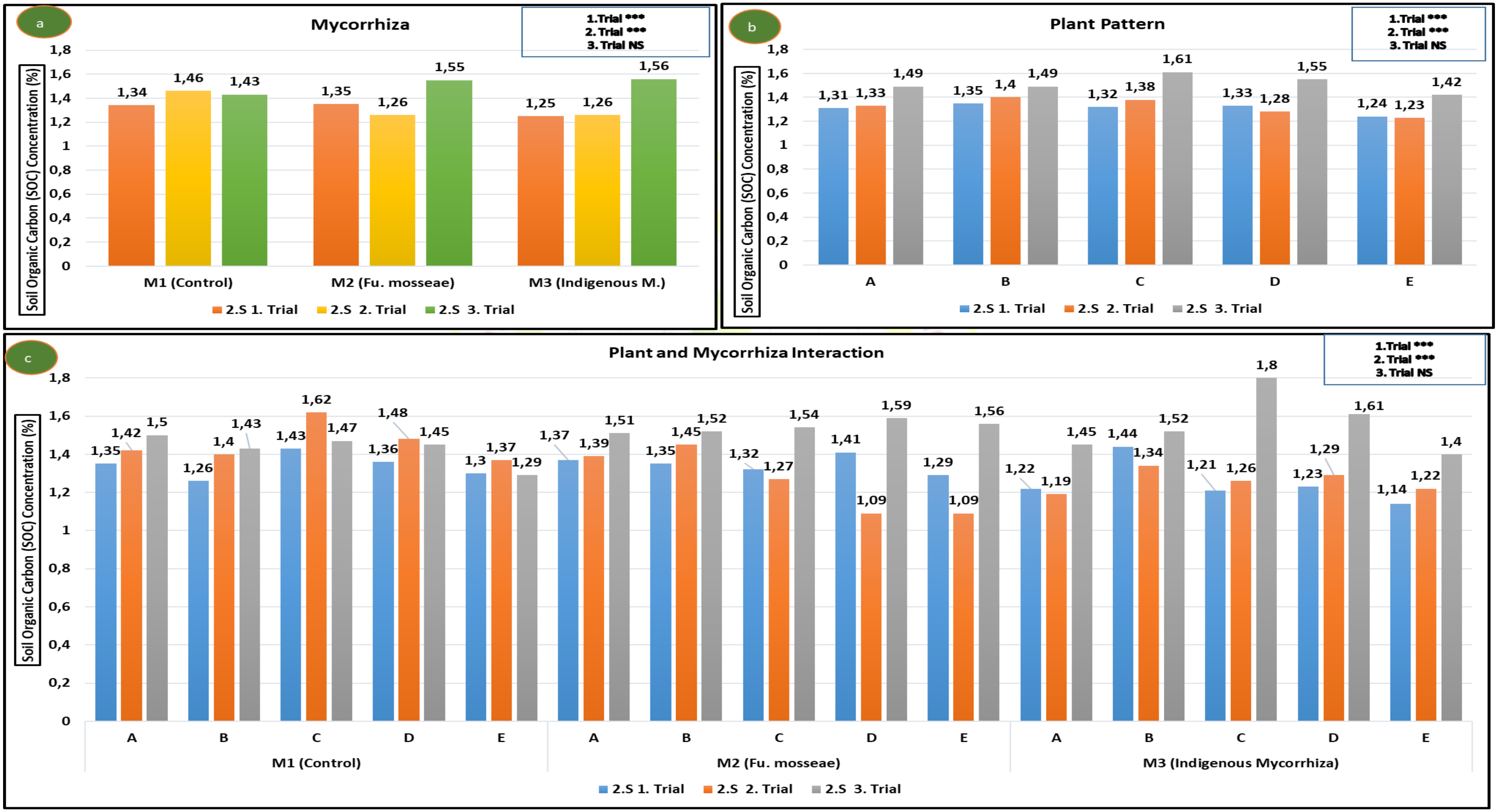

Figure 3. Change in organic carbon content in Arık soil, the second soil, as a result of 3 consecutive trials of different mycorrhiza inoculation and different cover crops.
a: Averages of mycorrhiza applications b: Averages of plant patterns c: Averages of mycorrhiza*plant interaction NS: Non-significant *: p<0.05, **:p<0.01, ***:p<0.001

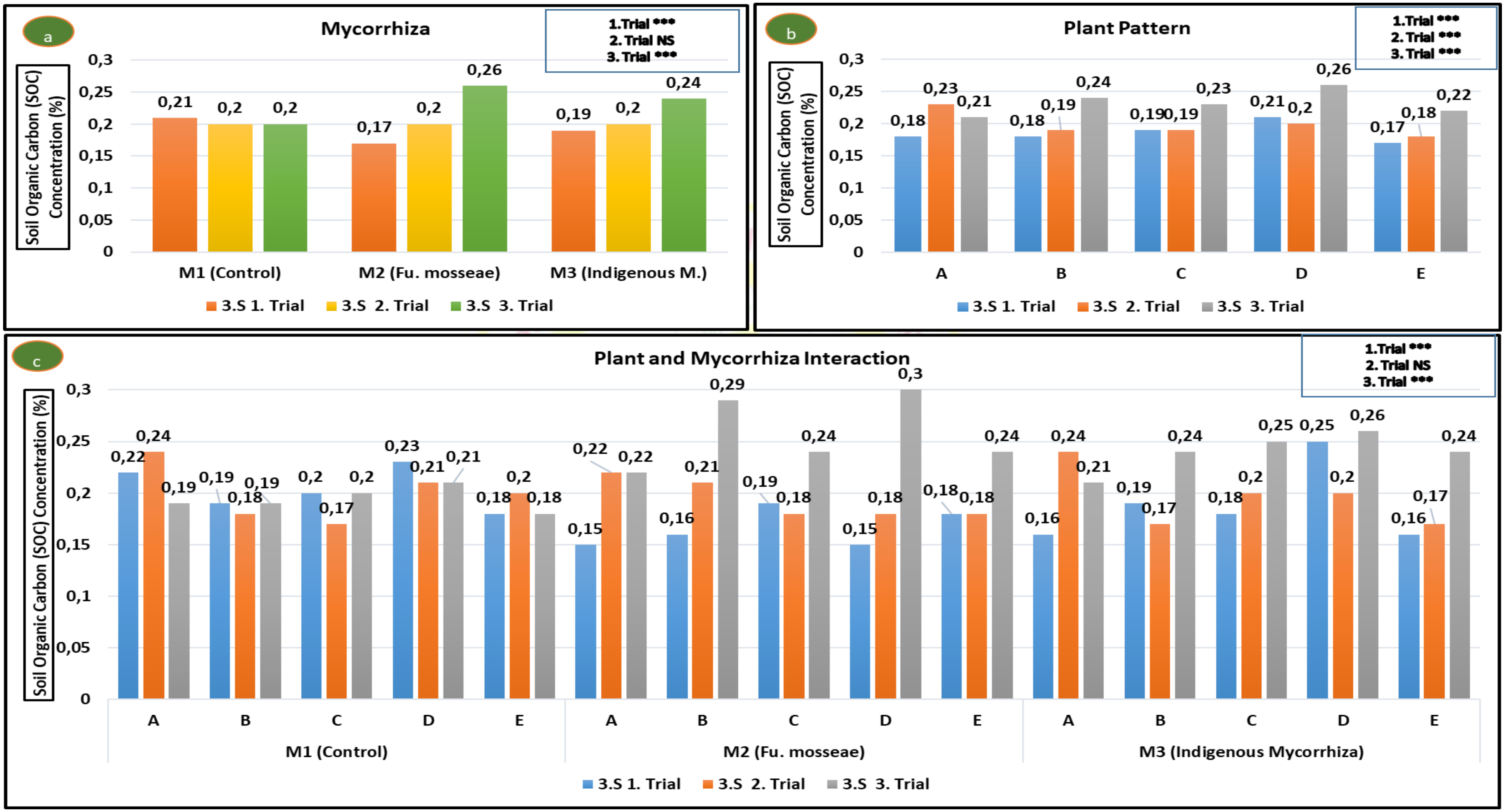

Figure 4. Change in organic carbon content in Avadan soil, the third soil, as a result of three consecutive trials of different mycorrhiza inoculation and different cover crops. a: Averages of mycorrhiza applications b: Averages of plant patterns c: Averages of mycorrhiza*plant interaction NS: Non-significant *: p<0.05, **:p<0.01, ***:p<0.001

Studies have reported that the symbiotic relation of cover crops and mycorrhizae has an important effect on increasing the SOC content. Cover crops provide organic matter to the soil through both the biomass on the surface and root residues, which then break down and form soil organic carbon. Cover crops increase microbial activities and support the carbon cycle. Cover crops strengthen the soil's organic carbon pool (Lal, 2007).

Long-term cover crop applications increase the total carbon content and active carbon forms of the soil and positively affect the nutrient cycle (Quintarelli et al., 2022; Zhang et al., 2023) Our results are supported by the data of (Leng et al., 2024), in which under long-term no-till systems, crop species diversification accumulated SOC not only on the surface but also in the whole profile. This means plant species accumulate organic carbon after root decomposition. In a different study, it was observed that cover crop plants increased the amount of easily oxidizable organic carbon in the soil. It was stated that in soils where legumes (e.g., broad beans) were used, easily oxidizable organic carbon levels were higher than those in soils with other cover crop plants. This situation was associated with the increased diversity of organic matter in the soil due to the symbiotic relationships of legumes. Furthermore, it was also reported that legume plants significantly improved soil microorganism activities (FDA enzyme activity) (Kabalan et al., 2024)

Mycorrhizae directly contribute to increasing the carbon content of the rhizosphere and mycorrhizosphere. Mycorrhizae produce glomalin-like soil proteins, which increase the physical stability of the soil and allow carbon to remain in the soil for longer periods. In addition, mycorrhizal fungi provide more carbon in the root zone of cover crops and help preserve soil organic carbon by regulating the rate of carbon decomposition. (Zhang et al., 2023).

Cover crop plants also play an important role in reducing greenhouse gas emissions through the mitigation of CO_2. Another study reported that cover crops can also reduce greenhouse gas emissions by reducing nitrate, nitrogen fixation to the soil, increasing carbon retention in the soil and reducing soil erosion. (Topçu et al., 2020). Organic carbon improves the physical condition of the soil and consequently reduces net CO_2 emissions. (Lal, 2007; Wallace et al., 2012).

To apply the research's results, it is important to test the findings with field experiments over longer periods. Moreover, our results indicate that similar experiments need to be conducted under field conditions.

CONCLUSION

After the experiments were conducted in all three soils, the data obtained were examined. It appears to be an increase in the soil organic carbon content from the first to the third experiments. When the effects of mycorrhizal inoculation were examined, the effect of the selected mycorrhizae species and indigenous mycorrhizae were positive compared to the control treatments. When the organic carbon values were obtained in all three soils, the highest results were found in the Havutlu soil, and the lowest was in the Avadan soil. Using these two applications together can be an effective strategy for increasing the organic carbon content of the soil in sustainable agricultural systems while supporting ecosystem services and combating climate change. Conducting long-term field experiments is recommended for a clearer understanding of the effect of cover crops and mycorrhizae.

CONFLICT OF INTEREST

The author here declares that there is no conflict of interest in the publication of this article.

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